BULLETIN

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IMPERIAL EARTHQUAKE INVESTIGATION COMMITTEE.

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CONTENTS.

On the Estimation of the Time of Occurrence at the Origin of a Distant Earthquake from the Duration of the 1st Preliminary Tremor observed at any place.

By

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Member of the Imperial Earthquake Investigation Committee.

The approximate time of occurrence ($=t_0$) at the origin of a distant earthquake can be calculated from the duration of the 1st preliminary tremor ($=y_1$) of the latter observed at any place. Thus, let T denote the time interval taken by the initial vibrations of the earthquake motion in travelling the arcual distance ($=x$), between the origin and the given station; and let v_1 and v_2 denote the velocities of propagation corresponding to the 1st and 2nd preliminary tremors. Then we have:—

$$v_1=\frac{x}{T};\ v_2=\frac{x}{T+y_1};\ \frac{v_1}{v_2}=1+\frac{y_1}{T}.$$

Putting proper values for v_1 and v_2, namely, $v_1=13.7$ and $v_2=7.2$ km. per sec.*, we obtain:—

$$T=1.108\,y_1\text{..........................}(1)$$

The values of v_1 and v_2 used in deducing the above formula are those obtained by "difference method," that is to say, calculated by taking the differences of the epicentral distances of different observing stations, and the differences of the times of arrival at the latter of the earthquake motion. For our present purpose,

* These values are slight modifications of those given in the "Publications," No. 13.

however, it is perhaps better to take the values of the transit velocities deduced by "direct method", or those obtained by dividing the epicentral distance of a station by the time interval taken by the seismic waves in traversing that distance.‡ The results deduced from the observations of the Indian earthquake of April 4, 1905, at different seismological stations, are as follows* :—

$$v_1 = 10.6 \text{ km. per sec.;}$$
$$v_2 = 5.83 \quad ,, \quad ,,$$

Using these values we obtain :—

$$T = 1.222\, y_1 \quad \ldots\ldots\ldots\ldots (2)$$

Let us provisionally take the mean of the two equations, thus:—

$$t_0 = t_1 - 1.165\, y_1 \ldots\ldots\ldots\ldots (3)$$

in which t_1 denotes the time of commencement of the earthquake motion at a given observatory.

Equation (3), which is to be regarded as being roughly approximate, gives fairly good results, as shown by the following examples.

(1) *Indian Earthquake of April 4, 1905.*

The time($=t_1$) of occurrence in Tokyo of this earthquake was $0^h\ 59^m\ 13^s$ (G. M. T.); the duration ($=y_1$) of the 1st preliminary tremor being 7m 16s. From (3) we thus find, for the time of earthquake occurrence at the centre itself:—

‡ See next Article.

* Deduced from the observations at the different stations, whose epicentral distance varied between 20° and 120.°

$$t_0 = 0\ 59^m\ 13^s - (1.165 \times 436^s) = 0^h\ 50^m\ 45^s \text{ (G. M. T.)}$$

This agrees very well with the time of occurrence at the origin inferred from the magnetograph observations made at Dehra Dun, namely, $0^h\ 49^m\ 48^s$ (G. M. T.)

(2) *San Francisco Earthquake of April* 18, 1906.

The time (t_1) of occurrence in Tokyo was $5^h\ 24^m\ 35^s$ A.M. (in Western States, or Pacific, Time); the duration ($=y_1$) of the 1st preliminary tremor being $9^m\ 49^s$. For the time of occurrence at the origin itself, we have:—

$$t_0 = 5^h\ 24^m\ 35^s - (1.165 \times 9^m\ 49^s) = 5^h\ 13^m\ 5^s \text{ A.M.}$$

This seems to be very close to the real value of t_0, since the time of occurrence of the great earthquake observed at the Students' Observatory, Berkeley, and Lick Observatory, Mount Hamilton, were respectively $5^h\ 12^m\ 39^s$ and $5^h\ 12^m\ 12^s$, these two places being not much distant from the epicentral zone. The time of earthquake occurrence at the centre of disturbance was probably $5^h\ 12^m$.

(3) *Calabrian Earthquake of Sept.* 8, 1905.

The time (t_1) of occurrence in Tokyo of the seismic motion was $1^h\ 56^m\ 09^s$ (G.M.T.); the duration (y_1) of the 1st preliminary tremor being $10^m\ 25^s$. Applying these values to our formula, we obtain:—

$$t_0 = 1^h\ 56^m\ 09^s - (1.165 \times 625^s) = 1^h\ 44^m\ 00^s \text{ (G.M.T.)}$$

Now according to the seismographical observations made at the Observatory of Messina, the earthquake shock was felt there first at

$1^h\ 43^m\ 17^s \pm 2^s$ (G.M.T.). Hence the time of occurrence at the origin itself was probably about $1^h\ 43^m\ 00^s$, which is close to the result estimated above.

On the Methods of Calculating the Velocities of Earthquake Propagation.

By

F. Omori, Sc.D.,

Member of the Imperial Earthquake Investigation Committee.

In the *Publications of the Earthquake Investigation Committee*, Nos. 5 and 13, I have stated the view that the seismic waves corresponding to the different phases of the earthquake motion are propagated along, or parallel to, the earth's surface.

In the discussion of the transit velocities of the different phases of the earthquake motion, given in subsequent Articles, I have followed the same assumption and used throughout the arcual distance instead of the length of the chord. Further, there are two distinct methods of the velocity calculation, as follows.

(*A*) ***Direct Method***, in which the transit velocity is obtained by dividing the epicentral distance of a station by the difference between the times of occurrence of a particular phase of motion at the latter and the origin of disturbance. Thus, if x' be the epicentral distance of a place, and if t' and t_0 be respectively the times of occurrence at the latter and the epicentre, we have:—

$$\text{Velocity} = \frac{x'}{t' - t_0}.$$

(*B*) ***Difference Method***, in which the velocity is obtained by dividing the difference of the epicentral distances of any two stations by the difference of the times of occurrence of a given phase of motion at these stations. Thus, if x' and t' have the

same meaning as before and if x'' and t'' be the corresponding quantities at a second place, we have:—

$$\text{Velocity}=\frac{x'-x''}{t'-t''}=\frac{\delta x}{\delta t}.$$

The "difference method" gives always a higher value of the velocity than the "direct method"; the discrepancy, which becomes smaller with the increase of the epicentral distance, being markedly shown up to the distance of about 40°.

In the "difference method," we have no need of ascertaining the time of occurrence at the origin of disturbance; the inaccuracy about the position of the epicentre being also avoided in a great measure, provided those stations which are taken for combination lie on one and the same great circle passing through the epicentre, on one side of which they are all situated.

The velocities corresponding to the commencement of the different phases of the earthquake motion will be denoted in subsequent Articles by the same symbols as in my former papers,* namely, as follows:—

v	Velocity of the	1st	preliminary	tremor;
v_2	,,	2nd	,,	,, ;
v_3	,,	1st	phase,	Principal Portion;
v_4	,,	2nd	,,	,, ;
v_5	,,	3rd	,,	,, ;
v_6	,,	4th	,,	,, ;
v_7	,,	5th	,,	,, ;
v_8	,,	6th	,,	,, .

* The "Publications," Nos. 5 and 13.

Preliminary Note on the Cause of the San Francisco Earthquake of April 18, 1906.

By

F. Omori Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

1. ***Introduction.*** The great earthquake of April 18, 1906, which caused an enormous amount of damage in San Francisco, furnished a rare opportunity of studying the different earthquake phenomena, especially the seismic effects on various modern structures. Immediately upon the receipt of the news of the catastrophe, the Imperial Government resolved to dispatch to California Professors T. Nakamura and T. Sano, and myself, for the purpose of making investigations on the great seismic disturbance, each according to his professional point of view. The party departed from Tokyo on May 1st, and arrived at San Francisco on the 18th of the same month, the present writer remaining about 80 days in California.

My special thanks are due to Professor George Davidson, and also to Professors Lawson and Leuschner of the University of California, Dr. Gilbert, of the U. S. Geological Survey, Mr. K. Uyeno, Japanese Consul, and other American and Japanese gentlemen, with whom I came in contact and who gave me most cordial assistance during my stay in California.

2. ***Time of Occurrence.*** The times of earthquake occurrence observed at the Berkeley University and the Lick Observatory were respectively $5^h\ 12^m\ 39^s$ and $5^h\ 12^m\ 12^s$ A.M. (Western States Time, or that of longitude 120° W.); the time of commencement of the

disturbance at the origin itself being probably about 5^h 12^m A.M.

3. *Area of Destructive Motion.* The area, within which more or less damage was done, was very long, extending over a distance of 550 miles along the Pacific coast, from the vicinity of Salinas on the south to the vicinity of Eureka on the north. The width or the extent from the coast of the strong motion area is probably some 50 miles. The earthquake of April 18th was thus greater, in length, than the large Japan earthquake of 1891, the length of whose area of strong motion was about 400 miles. The intensity of motion in the San Francisco earthquake was, however, less violent than in the other, and the amount of the casualties in San Francisco and the different parts of the strongly shaken zone was small comparatively.

4. *Sea Waves.* When an earthquake of inland origin is large and violent, the waters of ponds, rivers or lakes are more or less disturbed. So similarly a great submarine earthquake is often followed by tidal waves; the time interval between the occurrence of the earthquake shock and the arrival of the destructive sea waves varies from a few minutes to several hours, and depends on the distance of the origin from the shore. Tidal waves which are not to be noticed on high seas are developed most markedly in bays with shallow waters and an open mouth, but are quite insignificant along deep-water straight coasts. Many of the great earthquakes originating off the Pacific coast of Alaska and Central and South America have been accompanied by large tidal waves. But fortunately, this phenomenon which sometimes causes more damage than the earthquake disturbance itself was so far not very destructive along the coast of the United States. The great earthquake of April 18th last produced distinct, but very small disturbances of the bay waters which were clearly recorded on the

tide gauge at the Presidio (San Francisco); the amount of the rise and fall of the sea water being only about 6 inches, repeated in about 40 minutes. Now the wave period or periods at a place on a given coast remain constant in all the tidal waves, irrespective of the origin or cause; a destructive tidal wave consisting simply in the increase of the amount of the water motion existing more or less at all times, in consequence of a strong submarine earthquake or eruption, a storm, or some other agency. A seismic tidal wave is caused by the movements communicated from the sea bottom to the superincumbent water mass: a very big water disturbance taking place when the earthquake focus is at the sea bottom itself or at a very small depth below it, accompanied by some changes in the contour of the sea bottom. The absence of any great tidal disturbance on April 18th shows that there was no great submarine depression or vertical dislocation, although it seems probable that the northern half of the epifocal zone was under the Pacific.

5. *Sea Shock.* The steamer "Argo" felt the earthquake shock on sea near Cape Mendocino, the sensation being like that caused by running aground. There were other vessels which experienced the earthquake in a similar manner.

Effects like these, which may be called "sea-shocks," are due to the direct transmission through water of vibratory earthquake movements, and not due to the phenomena of the tidal waves which are developed only along coasts where there is some indentation.

6. *Approximate Position of the Centre of Epifocal Zone.* A *rough* idea as to the position of the most central or principal point in the zone, which forms the origin of the earthquake, may be obtained from a good seismograph record taken at the Lick

Observatory, where the preliminary tremor lasted about 10 or 12 seconds, from which it may be calculated that the distance between the point in question and Mt. Hamilton was about 80 or 90 miles; the predominating direction of motion there being NNW and SSE. These data indicate a place near the Tomales Bay as the most central point of the disturbance. The approximate position of the latter may be assumed to be at a point, *latitude* 38°15′N, *longitude* 123°W.

7. *The Epifocal Zone.* One of the peculiar features in the topography of the State of California is a straight depression whose direction is NNW and SSE and which extends through the valley of the Gualala River, and Tomales and Bolinas Bays, continued further south-eastwards for some distance. This depression, which must have been formed in bygone ages by a great sudden convulsion of the earth's crust, or by the gradual mountain-making force going along the Pacific Coast, shows signs of dislocations caused at no very remote epoch by some great earthquakes, and it is of a special interest that the earthquake of April 18th again produced along the same old weak zone a continuous series of remarkable surface manifestations of cracks, depression, or horizontal slipping, constituting what is called a "fault" in geology. This fault which has been most carefully studied by Dr. Gilbert of the U. S. Geological Survey, Professors Lawson and Branner, and other able geologists of the Berkeley and Stanford Universities, begins on the north at the right-hand mouth of the Alder Creek, near Pt. Arena, and, passes into the ocean at the vicinity of Fort Ross; it again appears at the Bodega Head and at the eastern side of the mouth of Tomales Bay, crosses to Inverness on the west shore of the same bay, and then passes through the vicinity of Pt. Reyes Station, continued to a

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Fig. 1. San Francisco and the Vicinity.
Showing the Course of the Great Fault, from Pt. Arena to Chittenden.

PL. I.

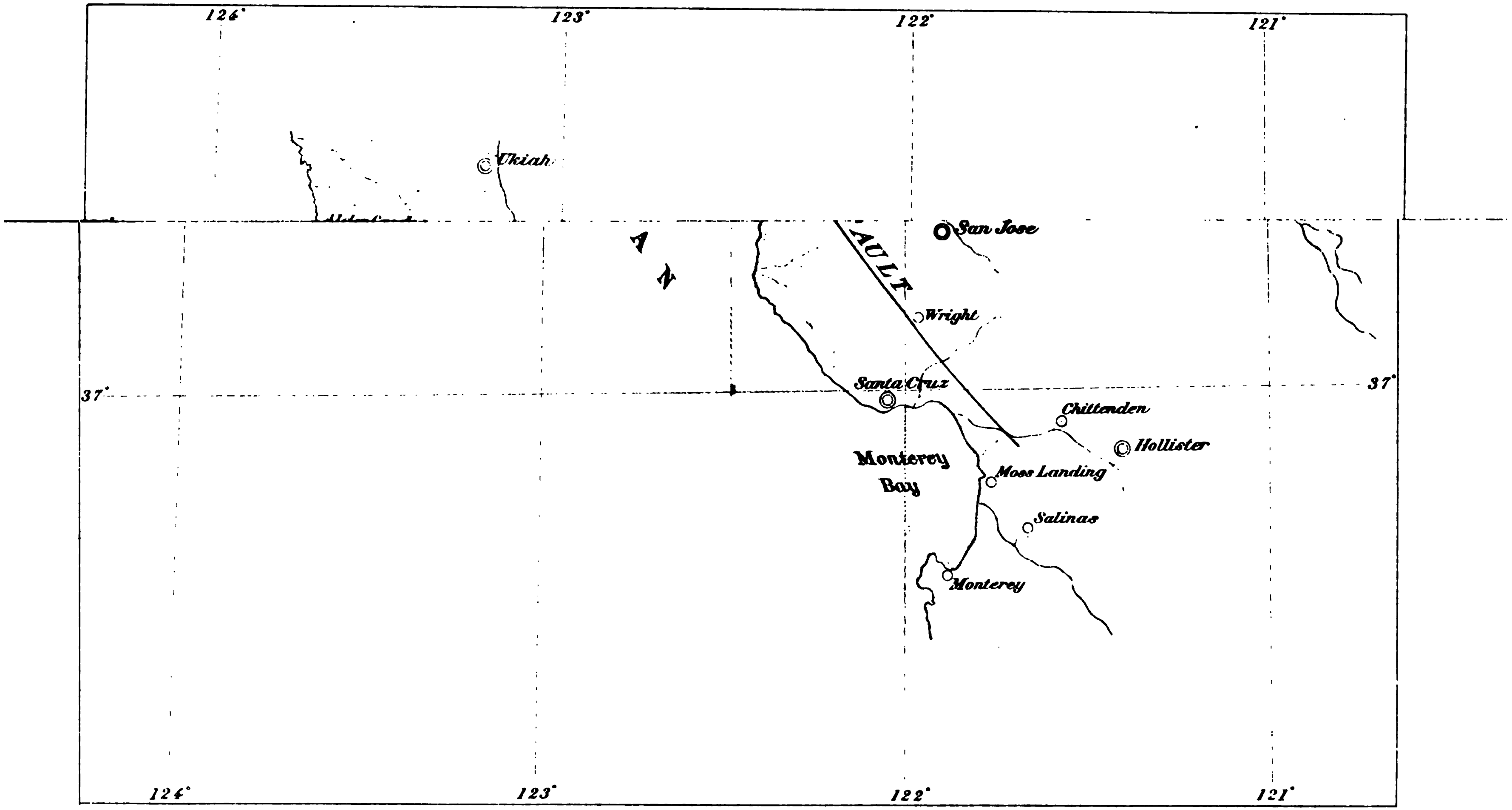


Fig. 2. San Francisco and the Vicinity, showing the General Course of the Great Fault.

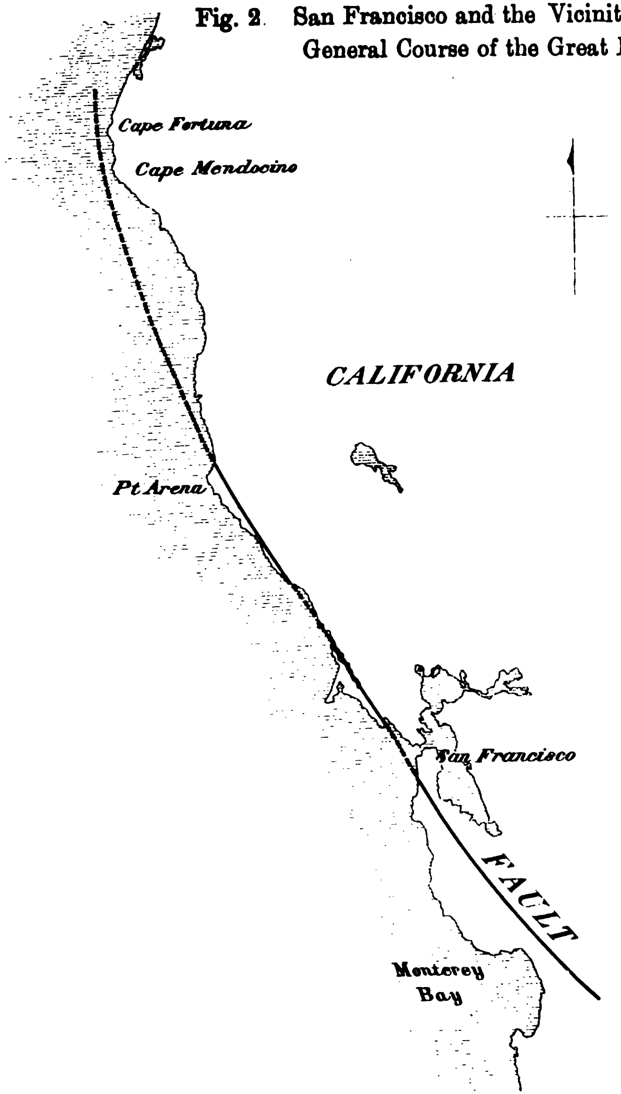
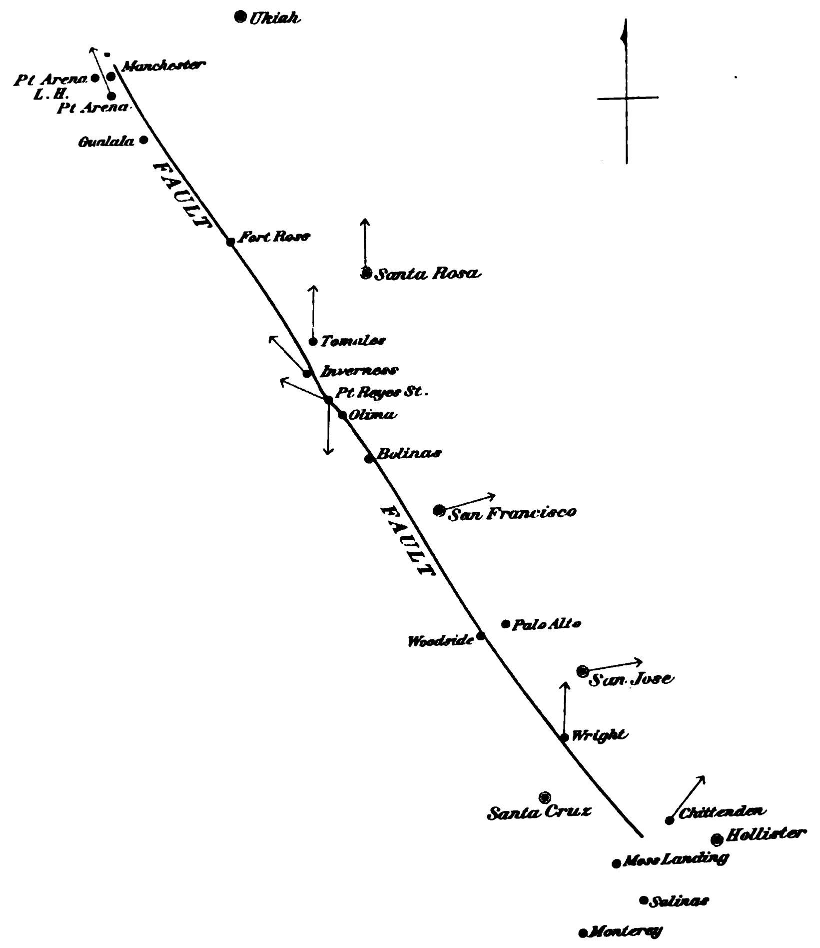


Fig. 8. Directions of Motion at Different places on or near the Great Fault.



place about 4 miles to the west of the Stanford University; marked disturbances of the ground being also distinctly shown to the south-east, in the vicinity of Wright and Chittenden. The length of the visible fault is thus over 150 miles, being three times that of the fault line in the great Japan earthquake of 1891. It is, further, extremely probable that the north-western part of the present fault is continued beyond Pt. Arena under the Ocean some 120 miles more and extends to the vicinity of Cape Fortuna. That the fault was not a mere surface phenomenon is shown by the appearance of the same disturbance across the tunnel near Wright Station, at a depth of some 700 feet below the mountain surface. See fig. 1 (Pl. I) and fig. 2 (Pl. II).

8. ***Shear of the Ground.*** The shearing movement of the ground produced many remarkable results; roads, fences, and every other thing crossed by the line of disturbance being cut apart and displaced considerably. There were cases, in which even large redwood trees were split by the shearing motion of the ground.

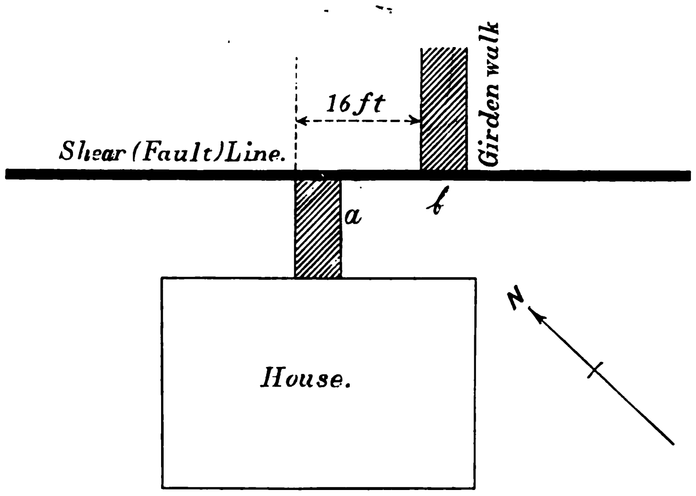


Fig. 4.

Figure 4 relates to the shear effect observed near Olima, a village situated between the Tomales and Bolinas Bays. The fault passed just in front of a house

(Skinner's Ranch) and produced a relative displacement of 16 feet, a girden walk being carried through that distance from *a* to *b*.

Fig. 11 (Pl. III) shows the shearing effects on a pier at Inverness, on the west coast of the Tomales Bay. The end part of the pier was separated from the rest and was displaced about 20 feet towards NNW. The direction of displacement in this particular instance was opposite to the general direction of the relative slip along the great fault line.

Fig. 12 (Pl. III) shows one of the fault cracks produced among the hills above Fort Ross. It will be observed that the new disturbances appeared along a depression marked by a series of small ponds (shown at the right-hand side of the picture), these latter being traces left by a former great earthquake.

Fig. 13 shows the remarkable compression and shear effects along one of the parallel fault cracks, observed on elevated grounds near the town of Manchester, not far from Pt. Arena. A foot-scale placed in the foreground will show the size of the overlapping earth pieces, whose plan is given in fig 8.

9. *Remarks on Shearing Movements.* For the sake of illustration, let us first consider cracks of a wall when the earthquake motion is parallel to the latter.

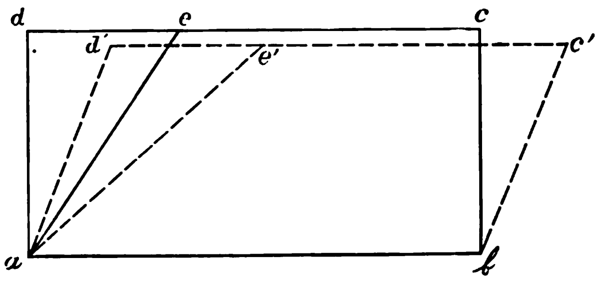


Fig. 5

Let *a b c d* (fig. 5) be a wall whose bottom side *a b* is fixed, either absolutely or relatively, while the upper side *c d* is brought to the position *c'd'* as the result of a shearing stress in the direction of *a* to *b*. Then the rate

of the length change of the line *ae*, connecting *a* with any point *e* on the side *cd*, will be greatest when the angle *dae* is equal to 45°. Consequently there will be formed a series of cracks at right angles to the lines of greatest elongation and at an angle of 45° to the base *a b*.

Thus, in the case of a strong horizontal motion parallel to the plane of the wall, there will be two sets of cracks at right angles to one another, as in Fig. 6.

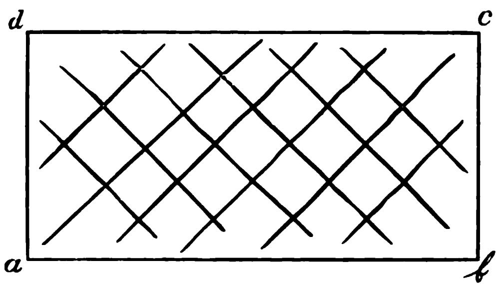


Fig. 6.

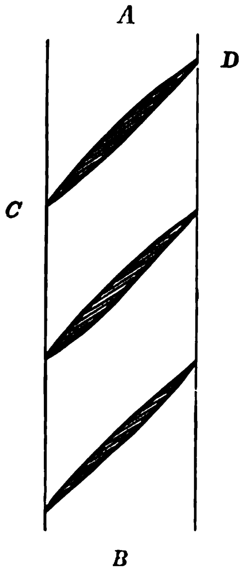


Fig. 7.

AB......Fault Zone.
CD......Shear Cracks.

Fig. 14 (Pl. IV) illustrates some of the cracks of plastered walls observed in St. James Hotel, San Jose.

Secondary Cracks of the Ground. Along the fault line the ground was, as in other cases, very often bulged up, forming a narrow zone of 1 or 2 feet elevation and some 5 or 10 feet width as if raised up by a gigantic mole creeping underground. This sort of ridge, whose formation was due to the shearing action, combined with a compression along the line of dislocation, showed usually a series of secondary oblique cracks, as is diagramatically indicated in Fig. 7. These ground cracks were perfectly similar to the shear cracks of walls considered above.

Figs. 8, 9 and 10, show parts of

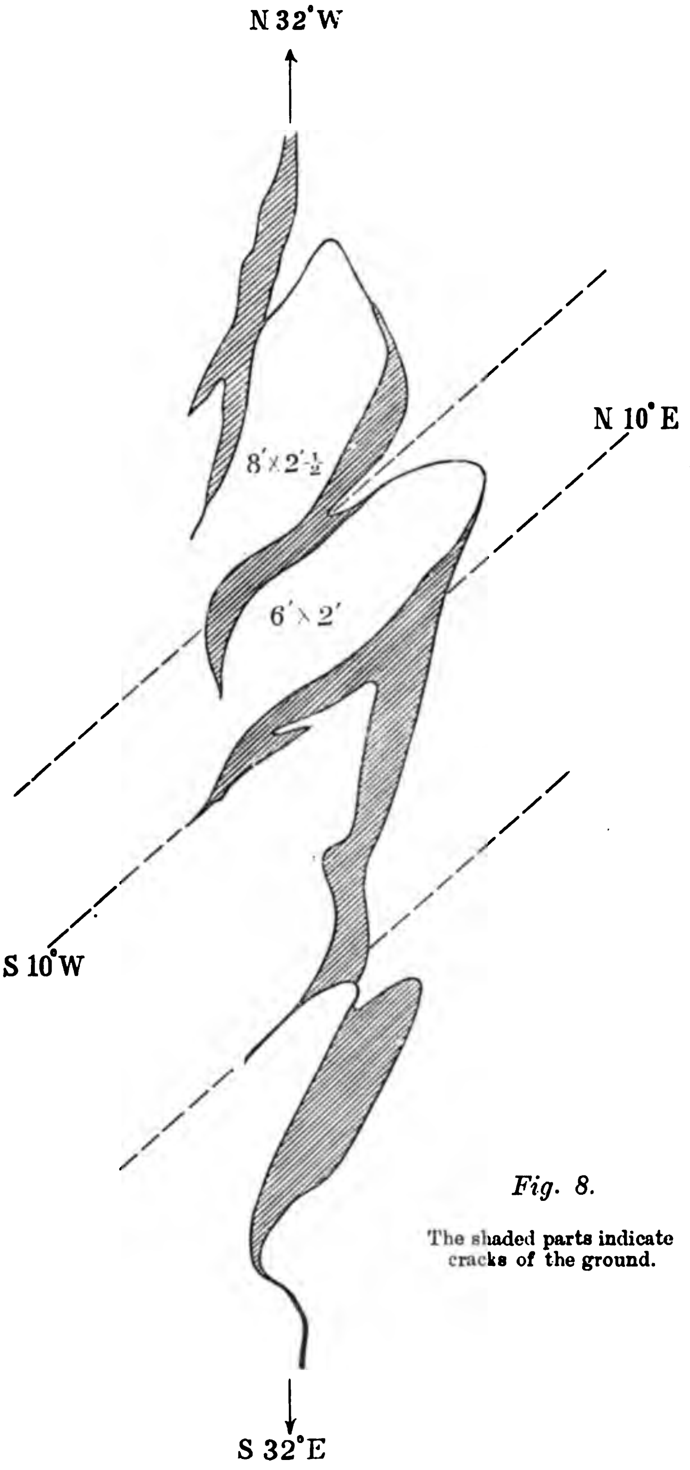


Fig. 8.

The shaded parts indicate cracks of the ground.

the fault lines found near the town of Manchester, not far from Pt. Arena; the dotted lines in each figure indicating the directions of the secondary shear cracks. Fig. 8 is the plan of the remarkable disturbances shown in Fig. 13. In Figs. 9 and 10, the angle between the main fault line and the shear cracks varied between 44° and 47°. In Fig. 8 however, there was evidently a very strong compression, and the shear angle was smaller, namely, 42°.

I have measured the shear angle in 11 other cases, where it varied between 35° and 47°; the total average value being 40°.

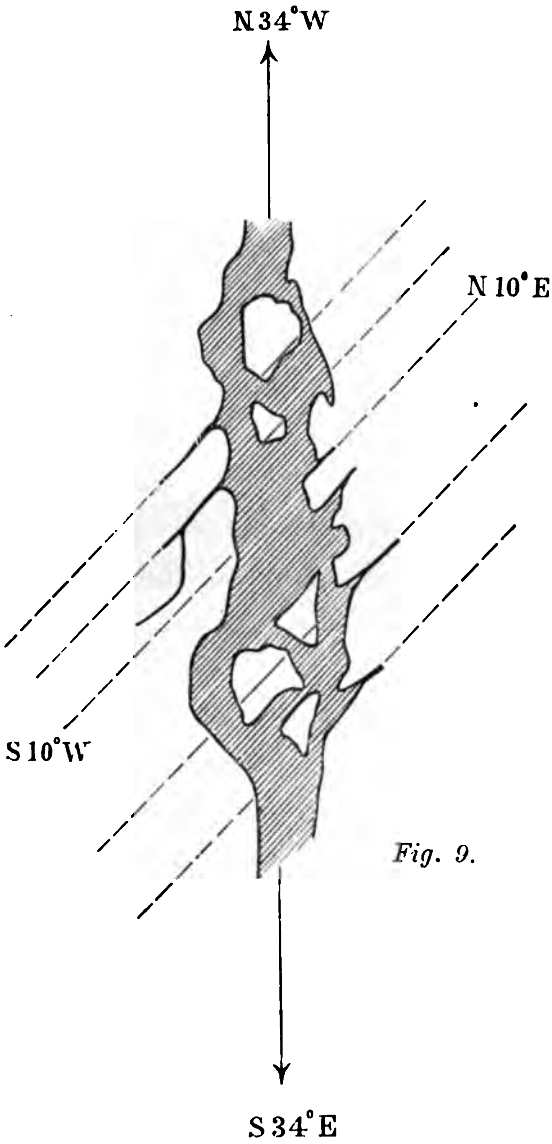


Fig. 9.

If the shear be accompanied by a horizontal compression at right angles to the fault line, the angle between the latter and the shear cracks will be smaller than 45°, as suggested by Professor A. Inokuty, of the Engineering College, Tokyo Imperial University. The coexistence of a tension normal to the fault plane will, on the other hand, make the same angle greater than 45°.

10. *Comparison with the Formosa Earthquake of March 17th, 1906.* The local but very severe earthquake in the Kagi Prefecture, Formosa, on March 17, 1906, produced also remarkable surface dislocations, in which the vertical depression and the horizontal shear each

amounted to about 8 feet. The angle between the direction of the main fault and that of the shear cracks was on the average 43°.

11. *Landslips, etc.* In the meizoseismal area, there were great many cases of mountain slides. The most remarkable among these was that which occurred near Cape Fortuna (False Cape), where an enormous quantity of debris was detached from a mountain side and was pushed into the Ocean, creating a new promontary of about 3/4 mile length.

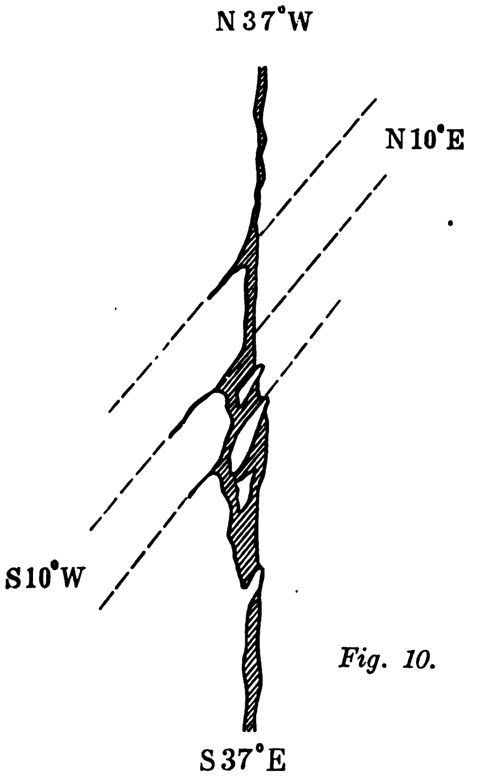


Fig. 10.

At Moss Landing, near Salinas, there were great horizontal disturbances of the sandy ground; the office of the station agent being displaced about 15 feet relative to the adjoining fence.

12. *Direction of Motion in San Francisco.* Fig. 19 (Pl. VII) shows the directions towards which 520 monuments at the different cemeteries in San Francisco and the vicinity were overturned by the earthquake shock. It will be observed that the greatest number of the monuments were overturned towards the east or east slightly north. The mean direction of overturning is N76°E, which may be regarded as the direction *toward* which the greatest horizontal displacement took place.*

See the "Publications," No. 4.

13. *Relation to the Great Fault of the Directions of Motion at the neighbouring places.* The approximate directions of the principal or strongest motion at the different places on or near the fault, each determined from numerous overturned bodies, were as follows:—

A.	San Francisco	N76°E.
	San Jose	N81°E.
	Chittenden...	N38°E.
	Watsonville	NE.
	Santa Rosa...	N.
	Tomales	N.
	Pt. Reyes Station(East side of Fault) ...	S.
B.	Pt. Arena	NNW.
	Inverness	NW.
	Pt. Reyes Station (West side of Fault) ...	WWN.
	Wright...	N.

The mean general direction of the fault is N 37° W—S 37° E, this being exactly identical with the direction of the great depression zone before mentioned. The places in Group *A* are situated on the eastern side of the fault line, while those in Group *B* are situated on the western side. It will thus be observed that at the *A* Group places the direction of motion was mostly towards North, North-East, or North-East by East; while at the *B* Group places, the direction was toward North-West, North, or North-West by West. Thus, on the whole, the motion on each side of the fault line had a tendency to diverge, or to be directed away, from the latter. This can be explained on the supposition of a subterranean collapse, or settling down, which would produce an initial inward motion, to be followed by the second and larger outward displace-

ment. Further, the directions of motion at the different places were mostly northward, and not southward. This would mean that the whole meizoseismal zone was first pushed towards SSE, the second or counter motion, which was greater, being consequently directed toward NNW. I presume therefore that the action, which caused the great earthquake of April 18th, was a sudden movement towards South-East by South of the earth's crust at the west coast of California, accompanied by some downward thrust. In this connection it is extremely interesting to note that Mount Tamalpais on the north shore of the Golden Gate has been ascertained, from the trigonometrical measurements, to have moved, between 1851 and 1882, 5.6 feet towards N 12° W, indicating that the earth's crust at this part of America was being strained toward the same direction. The ground on the eastern side of the fault line was generally displaced toward S S E relative to the ground on the other side; the amount of the horizontal slip was maximum at places between Pt. Arena and Pt. Reyes Station and varied from 16 ft. to 20 ft.; the amount of displacement decreasing to about 8 ft. at Woodside, near Stanford University, and to about 4 ft. in the vicinity of Wright. From the uniformity of northward direction of motion it is probable that both sides of the fault line were displaced toward NNW, but the west side was moved more than the east side, the amount of the horizontal slip, or shear, above mentioned being merely relative or differential. In the majority of cases the eastern side was depressed, the maximum amount being 2 ft.

14. From the comparatively very small number of after-shocks, I am inclined to suppose that the main source of the earthquake was situated some considerable depth below the surface. In fact the earthquake seems to have been caused by a

Fig. 11. The shearing effects on a pier at Inverness, on the west coast of the Tomales Bay. The end part of the pier was displaced about 20 feet towards NNW.

Fig. 13. Remarkable compression and shear effects along one of the fault cracks, produced on elevated grounds near Pt. Arena. A foot-scale placed in the foreground shows the size of the overlapping earth pieces, whose plan is given in fig. 8.

Fig. 12. One of the fault cracks produced among the hills above Fort Ross. The new disturbances appeared along a depression marked by a series of small ponds (shown at the right-hand side of the picture), which are traces left by a former earthquake.

Fig. 14. Some of the cracks of plastered walls, in St. James Hotel, San Jose.

Fig. 15. The damaged condition of the newly erected Library of the Stanford University. The central steel dome behaved as an elastic inverted pendulum.

Fig. 16. The ruined condition of a steel-framed brick house in San Francisco, which was dynamited and then burnt, showing the remarkable effects of the intense heat.

The Observatory on the top of the Strawberry Hill, in the Golden Gate Park, San Francisco, built of reinforced concrete.

Fig. 17. An outside view of the back part.

Fig. 18. One of the cracks of the basement wall. The steel cable, one inch in diameter, which was embedded in the concrete, was broken.

disturbance which took place along the old weak line but extended deeper into the earth's crust. The great depth of the main source of disturbance also explains why the intensity of motion was comparatively not very violent, and also why some places such as Santa Rosa, San Jose and Ferndale, not directly on the fault zone, were also badly shaken.

15. ***Earthquake Damage.*** This earthquake enabled us, for the first time, to study the effects of the shocks on steel-brick and reinforced concrete buildings; there being also numerous other damaged structures, such as ordinary brick, stone and wooden houses, bridges, water-pipes, etc. In San Francisco, the earthquake was followed by fires, which broke out from several places, continued for three days, and entirely destroyed the principal business quarters of the city. The total area of the burnt districts was 4.1 square miles, which is equivalent to 6 times the area of the great London fire of 1666. The amount of casualties was, however, comparatively small, the *ascertained* number of persons killed being about 390. The total number of the killed in the whole earthquake area was probably not more than 1000, the loss of life in Santa Rosa, Stanford University, and other strongly shaken places being slight. In San Francisco, serious damage was confined to the filled-up grounds, where the motion was not so strong as in the cities of Nagoya (max. acceleration=2600 mm. per sec. per sec.), Fukui (max. acceleration =2500 mm. per sec. per sec.), etc., on the occasion of the great Mino-Owari Earthquake of 1891. The double amplitude of motion in San Francisco was probably some 4 inches, and the complete period of vibration about 1 second.

Fig. 15 shows the damaged condition of the newly erected Library of the Stanford University. The central steel dome,

which is virtually an elastic inverted pendulum, evidently much vibrated, thereby causing destruction to loosely connected brick and stone parts of the building. The mortar used for cementing the masonry walls was of an exceptionally bad quality.

The damage to the City Hall of San Francisco was also principally due to the same two circumstances, namely, the vibration of its high steel tower, and the bad quality of mortar.

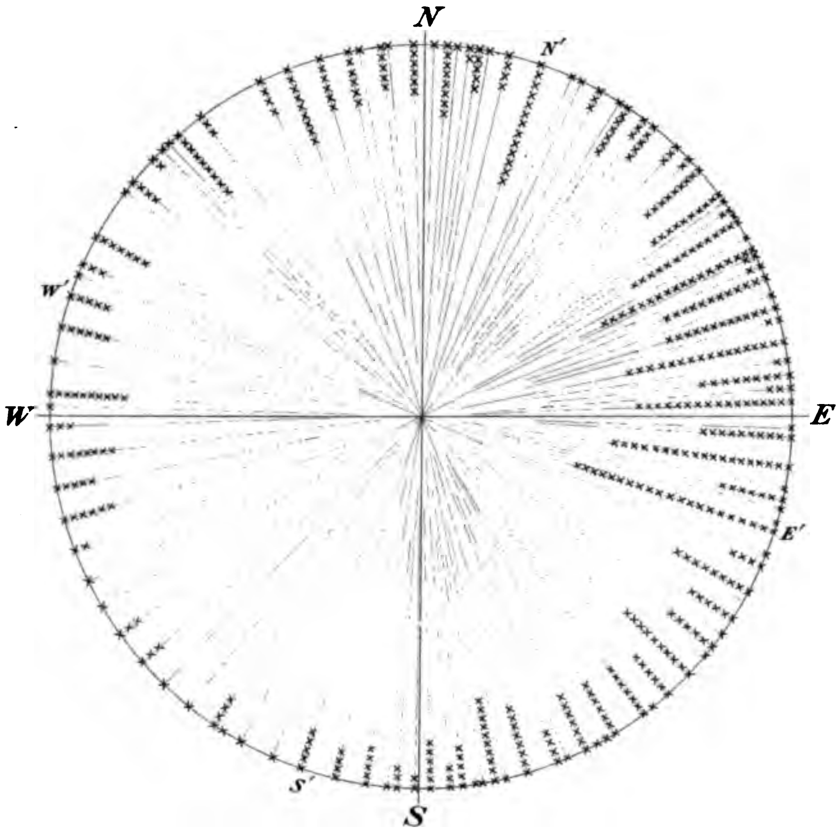
Fig. 16 (Pl. V) shows the ruined condition of a steel-framed brick house in San Francisco, which was dynamited and then burnt. The effects of the intense heat is remarkable, the steel frames being distorted in every possible form as if they had been formed of a soft maleable metal.

Fig. 17 (Pl. VI) gives an outside view of the back part of the Observatory on the top of the Strawberry Hill, in the Golden Gate Park, San Francisco. This building is of reinforced concrete and furnishes a good demonstration of the strength of such structures. The Observatory was indeed seriously damaged and its front portion fell down to the ground, but this was on account of the weakness of the foundation ground which was mostly a filled-up one and was considerably cracked and depressed. Fig. 18 shows, in a larger scale, one of the cracks of the basement wall, similar to that shown in Fig. 17. The steel cable, one inch in diameter, which was embedded in the concrete, was broken. The use of steel cables in concrete walls thus seems to be objectionable, as they are more liable to rusting than solid steel bars. None of the latter used in the concrete walls and floor of the Observatory, whose section was half inch square, was found broken ; the adhesion of concrete and steel being also very good.

16. ***Recent Seismic Activity.*** Recently there have been a

Fig. 19. Diagram showing the overturning directions of 520 Monuments in San Francisco and the Vicinity.

[Each small cross (×) indicates a monument overthrown in the direction of the radius on which it lies.]



N', E', S', W', indicate the 4 *magnetic* cardinal directions.

number of great earthquakes in different parts of the world, especially along the following two zones :—

(A). The Pacific coast of North and South America.

(B). Himalayas and North Mediterranean zone.

Next two §§ give a short account of the earthquakes belonging to these two zones.

17. *Earthquakes along the West Coast of North and South America.* Within the 7 years preceding the San Francisco earthquake of April 18, 1906, there were, along the Pacific coast of the American continents, seven great earthquakes, on the dates as follows :—

(i) Sept. 4 and 11, 1899 ; and Oct. 9, 1900.
(ii) Jan. 20, 1900 ; and April 19 and Sept. 23, 1902.
(iii) Jan. 31, 1906.

Of the above 7 earthquakes, the three of group (i) took place off the south-west coast of Alaska, two of them being accompanied by great tidal waves. The three earthquakes of the group (ii) strongly shook Mexico and Guatemala (Central America); while the earthquake of group (iii), which was accompanied by tidal disturbances, caused considerable damage in Panama, and the west coast of Columbia and Equador. The approximate positions of these three groups of earthquakes are marked in Fig. 20 by dotted lines, *1*, *2*, and *3*.

As the west coast of the American continents is one of the great seismic zones on the earth, it is to be supposed that the 7 destructive earthquakes above enumerated were not separate or local phenomena, but were the results of great stresses going on along the Pacific coast zone extending from Alaska to South America, manifested at its north and middle parts. Hence an event most naturally to be expected would have been the exten-

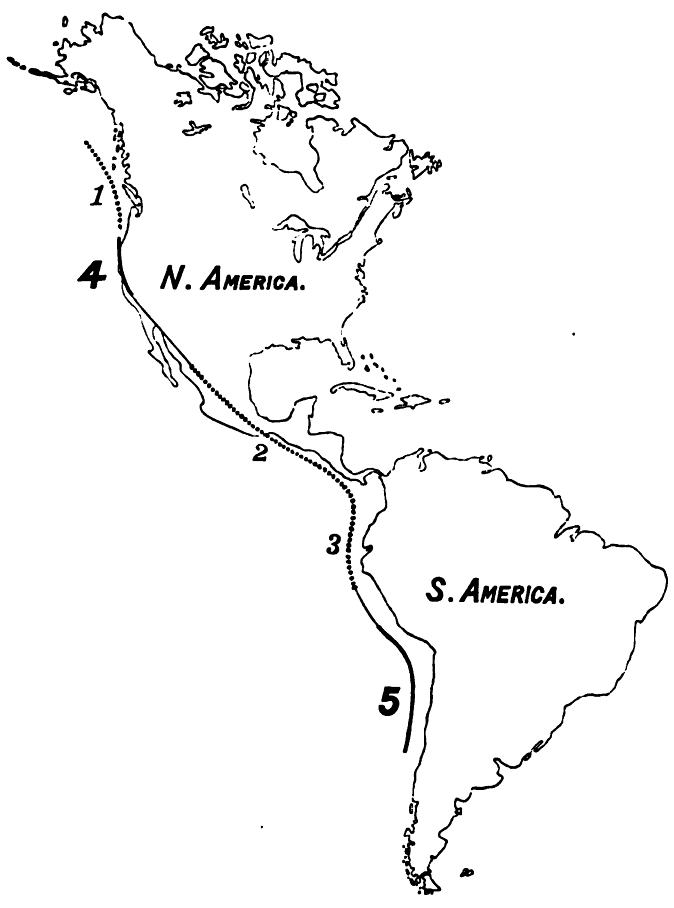


Fig. 20.

sion of the seismic disturbance to the west coast of the United States, which so far had been free from the visitation of disastrous earthquakes. Now this apprehended event has finally taken place on April 8 of this year, the approximate position of the origin being indicated in Fig. 20 by a thick line marked *4*. The great San Francisco earthquake may therefore be regarded as having completed the continuity of the seismic activity along these districts, which latter thus become, for a certain number of years, say 20 or 30 years, seismically a very safe place; *large* earthquakes, which remove a great unstability in the earth's crust, never happening successively at one and the same place.

During my recent stay in San Francisco I explained on several occasions reasonings like the above to newspaper reporters and others, also pointing out that even in the case of a future

destructive earthquake, the intensity of motion would not be extremely violent, so that a slight amount of precaution taken in building houses would ensure an almost perfect immunity from earthquake shocks. As to the probable position of the next great shock on the Pacific side of America, I expressed my view that it would be to the south of the equator (that is to say, Chile and Peru),* as it was very likely that the seismic activity would extend to either end along the great zone in question, and as the coast of the countries above named are often visited by strong earth convulsions. I departed on Aug. 4 from San Francisco for home, and arrived on the 22nd of the same month at Yokohama, first there learning of the disastrous shock of Valparaiso, which confirmed my anticipation. The approximate position of the origin of this last earthquake, which took place on Aug. 17 (1906) is indicated in Fig. 20 by a thick line marked *5*.

The great stresses going on along the whole Pacific coast of America, which thus resulted in the occurrence of a series of great earthquakes, seems to be connected with the growth of the Rocky and Andes mountain ranges; the Valparaiso earthquake bringing probably the *great* seismic activity along the zone under consideration for the time to an end.

18. ***Activity along the Himalayas and North Mediterranean Zone.*** With regard to the seismic activity in Asia and Europe, it is to be noted that the unusually severe eruptions of the Vesuvius, which began on about April 7th this year, lasted about one week, and ended on the 13th of the same month. On the following day, namely, April 14 (1906) there took place the destructive earthquake of Kagi District (Formosa), in which 1249 persons were killed. Four days later on there took place the great San

* This is what I published in the *San Francisco Bulletin* of June 13, 1906.

Francisco earthquake. Whether there existed or not a connection between the Vesuvian eruption and these earthquakes, it is a matter of fact that there was a great seismic activity along the whole length of the zone extending from the north coast of the Mediterranean to the Himalayas, and possibly to Formosa. The different earthquakes belonging to the zone in question, which happened recently, are as follows :—

(i) Assam and Bengal, (India), June 12, 1897.
(ii) Aidin (Smyrna), Sept. 20, 1899.
(iii) Schemacha (Caucasus), Feb. 13, 1902.
(iv) Kashugar (Turkestan), Aug. 22. 1902.
(v) Saloniki (Macedonia), April 4, 1904.
(vi) Kagi (Formosa), April 24, 1904.
(vii) ,, (,,), Nov. 6, 1904.
(viii) Kangra Valley (the Punjab, India), April 4, 1905.
(ix) Calabria (Italy), Sept. 8, 1905.
(x) Kagi (Formosa), March 17, 1906.
(xi) Kagi (,,), April 14, 1906.

Thus great earthquakes took place at the different parts of the zone stretching through Italy, Macedonia, Asia Minor, Caucasus, Turkestan, the outer side of the Himalayas, and Formosa; this proving that the underground stresses were growing along the whole zone. As the seismic disturbances above enumerated occurred in the same epoch as those belonging to the American zone, it is extremely likely that underground stresses reached a maximum all over the earth, resulting in a marked display of seismic disturbances along certain zones of weakness.

19. ***Conclusion.*** Future studies in various phenomena connected with the movements of the earth's crust might perhaps tend to advance our knowledge respecting the problem of the

prediction of great earthquakes, which are often preceded by what may be called "fore-shocks." In the meanwhile, and always, it will be necessary to build houses and other structures strong enough to resist earthquake shocks, a problem which presents no great difficulties.

Tokyo, Nov. 1, 1906.

Preliminary Note on the Seismographic Observations of the San Francisco Earthquake of April 18, 1906.*

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

1. In response to my circular asking for a copy of the seismographic or magnetographic records of the San Francisco earthquake of April 18, 1906, photographic or printed reproductions of the diagrams have been sent in from the following 35 stations :—*Lick Observatory ; Washington, D.C.; Cheltenham ; Tacubaya* (Mexico); *Victoria, B.C.; Toronto* ; *Honolulu ; Mizusawa ; Osaka ; Kobe ; Tadotsu ; Taihoku* (Formosa); *Paisley; Edinburgh ; Kew ; Shide* (Isle of Wight); *Strassburg ; Pola ; Quarto Castello, Querce and Ximeniano* (Florence); *Casamicciola and Porto d'Ischia,* in the Island of Ischia; *San Fernando; Tashkent ; Cairo* ; *Kodaikanal* (Madras) ; *Calcutta ; Dehra Dun; Batavia; Manila ; Zikawei* (Shanghai); *Wellington* and *Christchurch* (New Zealand); *Rio de Janeiro.* I take this opportunity of expressing my thanks to the seismologists in charge of these observatories for having so kindly supplied me with the results of their observations.

Table 1 gives a list of the latitude, longitude, epicentral distance, and the time of occurrence of the 1st preliminary tremor for Tokyo, and for each of the 35 above-mentioned stations, as well as 31 other places, namely :—*Berkeley; Ukiah* (California); *Baltimore; Baldwin* (Kansas); *Ottawa ; Vieques* (Porto *Rico*); *Sitka* (Alaska); *Bergen* (Norway); *Hamburg; Göttingen; Heidelberg; Jena;*

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* A note on the Tokyo observation of the San Francisco earthquake, with one of the seismograms, has been given in the *Publications of the Earthq. Inv. Comm.*, No. 21, App. II.

Krakau; Kremsmuenster; Vienna; Laibach; Budapest; O'Gyalla; Triest; Fiume; Zagreb (Croatia); *Sarajevo* (Bosnia); *Agram; Tortosa; Ebro; Cartuja* (Granada); *Belgrad; Sofia; Jurjew; Tiflis; Fremantle* (Australia). The times of commencement of the 1st and 2nd preliminary tremors relating to these latter places have been taken from Dr. Bauer's paper, entitled "Seismograph and magnetograph records of the San Francisco earthquake,"* and from the monthly or weekly reports of the different seismological observatories.

The velocities of propagation corresponding to the commencements of the 1st and 2nd preliminary tremors are denoted by v_1 and v_2; the calculation being made both according to the "direct method" and the "difference method", as explained in one of the preceding Articles. t_1 and t_2 denote respectively the times of commencement of the 1st and 2nd preliminary tremors at a given station, whose epicentral distance is x. t_0 denotes the time of earthquake occurrence at the origin.

In the calculation of the epicentral distance of a station, the position of the seismic origin has been fixed according to the preceding Article, at a point, *latitude* 38° 15′ N, *longitude* 123° W; the time of commencement of the earthquake motion at the origin being assumed to be $13^h\ 12^m\ 00^s$ G.M.T.

* The *Popular Science Monthly*, August, 1906.

TABLE I.—OBSERVATION OF THE SAN FRANCISCO EARTHQUAKE OF APRIL 18, 1906.

(*......Time determined from magnetograms.)

Place.	Position.		Epicentral Distance. $=x$	Time of occurrence (G.M.T.)
	Latitude.	Longitude.		
Origin	38° 15′ — N	123° — W	——	$13^h 12^m 00^s$
United States.				
University, Berkeley	37° 52′ 24″ N	122°15′11″ W	0° 42′	13 12 39
Lick Observatory	37° 20′ 25″ N	121°38′44″ W	1 24	13 12 12
Ukiah.	39° 08′ 12″ N	123°13′— W	0 54	13 12 17
Washington, D.C.	38° 54′ 18″ N	77°03′06″ W	35 32	13 19 20
Cheltenham	38° 44′ — N	76°50′30″ W	35 44	13 19 24 13 30 00*
Baltimore	39° 17′ 48″ N	76°37′12″ W	35 46	13 19 24
Baldwin	38° 47′ — N	95°10′— W	21 42	13 24 —*
Mexico.				
Tacubaya	19° 24′ 18″ N	99°11′37″ W	27° 57′	13 17 58
Canada.				
Victoria, B.C.	48° 27′ — N	123°22′— W	10° 12′	13 14 12
Toronto	43° 39′ 36″ N	79°23′24″ W	32 59	13 19 18
Ottawa	45° 26′ — N	75°40′— W	35 27	13 17 59
Porto Rico.				
Vieques	18° 09′ — N	65°26′— W	53° 38′	13 22 17
Alaska.				
Sitka	57° 03′ — N	135°20′— W	20° 29′	13 17 01 13 22 54*
Hawaii.				
Honolulu	21° 19′ — N	153°04′— W	30° 53′	13 19 30 13 27 48*
Japan.				
Mizusawa	39° 08′ — N	141°07′— E	70° 50′	13 24 07
Tokyo	35° 42′ 29″ N	139°45′53″ E	73 41′	13 24 35
Osaka	34° 42′ — N	135°31′— E	77 04	13 24 24

TABLE I.—*Continued.*

Place.	Position.		Epicentral Distance $=x$.	Time of occurrence (G.M.T.)
	Latitude.	Longitude.		h m s
Kobe	34° 41′ — N	135°11′— E	77° 17′	13 24 23
Tadotsu..................	34° 17′ — N	133°46′— E	78 27	13 25 07
Taihoku(Formosa) ..	25° 02′ — N	121°30′— E	92 33	13 27 20
Great Britain.				
Paisley	55° 51′ — N	4°25′— W	72° 27′	13 23 12
Edinburgh	55° 57′ 23″ N	3°10′46″W	72 53	13 23 30
Kew	51° 28′ 06″ N	0°18′46″W	77 17	13 25 42
Shide (New Port).....	50° 42′ — N	1°19′— W	77 25	13 25 00
Birmingham	52° 28′ — N	1°53′— W	75 54	13 25 03
Norway.				
Bergen	60° 30′ — N	5°25′— E	72° 38′	13 22 46
Germany.				
Hamburg	53° 33′ 55″ N	10°01′19″ E	79° 38′	13 24 32
Göttingen	51° 33′ — N	9°58′— E	81 15′	13 24 34
Heidelberg	49° 23′ 55″ N	5°58′44″ E	81 28	13 25 23
Jena	50° 56′ — N	11°35′— E	82 21	13 24 34
Strassburg	48° 35′ 00″ N	7°46′10″ E	82 49	13 24 56
Austria-Hungary.				
Krakau	50° 03′ 50″ N	19°57′36″ E	85° 51′	13 35 48
Kremsmünster.........	48° 03′ — N	14°08′— E	85 40	13 24 25
Vienna	48° 13′ 55″ N	16°20′23″ E	86 17	13 25 42
Laibach..................	46° 03′ — N	14°31′— E	87 29	13 25 25
Budapest	47° 22′ 29″ N	19°03′55″ E	87 56	13
O'Gyalla	47° 52′ 24″ N	18°52′32″ E	87 26	13 25 20
Pola	44° 51′ 49″ N	13°50′44″ E	88 15	13 25 56
Triest	45° 38′ 45″ N	13°45′45″ E	87 33	13 24 33
Fiume	45° 19′ 56″ N	14°25′40″ E	88 05	13 40 00
Zagreb	45° 48′ 54″ N	15°58′48″ E	88 13	13 25 25
Sarajevo	43° 52′ — N	18°44′— E	90 53	(?)
Agram	45° 50′ — N	16°08′— E	88 16	13 25 17
Italy.				
Quarto Castello	43° 49′ 11″ N	11°13′11″ E	88 '05	13 27 15
Querce	43° 47′ 18″ N	11°16′42″ E	88 08	13 25 00
Ximeniano	43° 46′ 46″ N	11°15′24″ E	88 08	13 26 25
Porto d'Ischia	40° 44′ 27″ N	13°56′34″ E	91 46	13 26 59

TABLE I.—*Continued.*

Place.	Position. Latitude.	Position. Longitude.	Epicentral Distance $=x$.	Time of occurrence (G.M.T.) h m s
Casamicciola	40° 44′ 45″ N	15°54′12″ E	91° 44′	13 26 08
Spain.				
San Fernando.	36° 27′ 40″ N	6°12′19″W	85° 14′	13 25 06
Tortosa	40° 49′ — N	2°34′ — E	86 37	13 24 55
Cartuja (Granada)	37° 10° 45″ N	0°05′25″ E	88 08	13 24 40
Ebro	40° 49′ 12″ N	0°29′40″ E	85 36	13 24 55
Servia.				
Belgrad	44° 48′ — N	20°09′ — E	90° 33′	13 36 54
Bulgaria.				
Sofia	42° 42′ — N	23°20′ — E	93° 28′	13 25 00
Russia.				
Jurjew	58° 25′ — N	26°42′ — E	80° 05′	13 24 39
Tiflis	41° 43′ 08″ N	44°47′51″ E	99 16	13 27 17
Taschkent	41° 19′ 31″ N	69°17′42″ E	99 38	13 28 05
Egypt.				
Cairo	30° 04′ 33″ N	31°17′14″ E	107° 35′	13 31
India.				
Kodaikanal	10° 13′ 50″ N	77°27′46″ E	127° 53′	13 31 36
Calcutta	22° 34′ — N	88°24′ — E	112 25	13 19 54
Batavia	6° 08′ — S	106°50′ — E	117 18	13 32 54
Manila	14° 34′ 41″ N	120°58′33″ E	100 14	13 22 42
Shanghai	31° 11′ 33″ N	121°10′45″ E	88 24	13 34 59
New Zealand.				
Wellington	41° 17′ — S	174°47′ — E	97° 40′	13 26 36
Christchurch	43° 31′ 50″ S	172°37′18″ E	100° 23′	13 33 36
Brazil.				
Rio de Janeiro	22° 54′ 24″ S	43°10′21″W	96° 30′	13 59 41(?)
Australia.				
Fremantle	32° 03′ — S	115°44′ — E	90° 58′	13 46 50

Table II gives the times of occurrence of the 1st preliminary tremor at the different stations, divided into a number of groups, according to the epicentral distance ; those places, whose time observations are apparently not quite exact, being *provisionally* excluded.

TAELE II.—SAN FRANCISCO EARTHQUAKE OF APRIL 18, 1906.

Different Stations divided into Groups.

Place.	Epicentral Distance $=x$.	Time of occurrence. $=t_1$(G. M. T.)
		h m s
Origin.	———	**13 12 00**
Victoria, B.C.	10° 12′	13 14 12
Sitka	20° 29′	13 17 01
Tacubaya	27° 57′	13 17 58
Honolulu	30° 53′	13 19 30
Toronto	32° 59′	13 19 18
Mean	**30° 36′**	**13 18 55**
Ottawa	35° 27′	13 17 59
Washington	35° 32′	13 19 20
Cheltenham	35° 44′	13 19 24
Baltimore	35° 46′	13 19 24
Mean	**35° 37′**	**13 19 02**
Vieques	53° 38′	13 22 17
Mizusawa	70° 50′	13 24 07
Tokyo	73° 41′	13 24 35
Osaka	77° 04′	13 24 24
Kobe	77° 17′	13 24 23
Mean	**74° 43′**	**13 24 22**
Bergen	72° 38′	13 22 46

TABLE II.—*Continued.*

Place.	Epicentral Distance $=x$	Time of occurrence. $=t_1$ (G. M. T.)
		h m s
Paisley	72° 27′	13 23 12
Edinburgh	72 53	13 23 30
Birmingham	75 54	13 25 03
Kew	77 17	13 25 42
Shide	77 25	13 25 00
Hamburg	79 38	13 24 32
Jurjew	80 05	13 24 39
Göttingen	81 15	13 24 34
Heidelberg	81 28	13 25 23
Jena	82 21	13 24 34
Strassburg	82 49	13 24 56
Mean	**78 01**	**13 24 29**
San Fernando	85° 14′	13 25 06
Ebro	85 36	13 24 55
Kremsmünster	85 40	13 24 25
Vienna	86 17	13 25 42
Tortosa	86 37	13 24 55
O'Gyalla	87 26	13 25 20
Laibach	87 29	13 25 25
Triest	87 33	13 24 33
Quarto Castello	88 05	13 27 15
Querce	88 08	13 25 00
Ximeniano	88 08	13 26 25
Cartuja (Granada)	88 08	13 24 40
Zagreb	88 13	13 25 25
Pola	88 15	13 25 56
Agram	88 16	13 25 17
Ischia*	91 45	13 26 34
Taihoku	92 23	13 27 20
Sofia	93 28	13 25 00
Mean	**88 09**	**13 25 31**
Wellington	97° 40′	13 26 36
Tiflis	99 16	13 27 17
Taschkent	99 38	13 28 05
Batavia	117 18	13 32 54
Kodaikanal	127 53	13 31 36
Mean	**108 21**	**13 29 18**

* Mean of Porto d'Ischia and Casamicciola.

2. *Velocity of Propagation of the 1st Preliminary Tremor.*

"DIRECT METHOD."

(i)* Victoria, B.C.

$$x=10°12'=1133\ km.$$
$$t_1=1^h14^m12^s$$
$$t_1-t_0=2^m12^s=132\ \text{sec.}$$
$$v_1=8.58\ km\ \text{per sec.}$$

(ii)* Sitka.

$$x=20°\ 29'=2276\ km.$$
$$t_1=1^h17^m01^s$$
$$t_1-t_0=5^m01^s=301\ \text{sec.}$$
$$v_1=7.56\ km\ \text{per sec.}$$

(iii) Tacubaya, Honolulu, Toronto :—

Mean...... $x=30°\ 36'=3400\ km.$
$$t_1=1^h18^m55^s$$
$$t_1-t_0=6^m55^s=415\ \text{sec.}$$
$$v_1=8.19\ km\ \text{per sec.}$$

(iv) Eastern Parts of Canada and the United States:— *Ottawa, Washington, D.C., Cheltenham, Baltimore.*

Mean...... $x=35°\ 37'=3956\ km.$
$$t_1=1^h19^m02^s$$
$$t_1-t_0=7^m02^s=422\ \text{sec.}$$
$$v_1=9.37\ km\ \text{per sec.}$$

(v)* Vieques (Porto Rico).

$$x=53°\ 38'=5958\ km.$$
$$t_1=1^h22^m17^s$$
$$t_1-t_0=10^m17^s=617\ \text{sec.}$$
$$v_1=9.66\ km\ \text{per sec.}$$

(vi) Japan:—*Mizusawa, Tokyo, Osaka, Kobe.*

Mean...... $x=74°\ 43'=8301\ km.$
$$t_1=1^h24^m22^s$$

$t_1-t_0=12^m22^s=742$ sec.

$v_1=11.19$ *km* per sec.

(vii) Norway, Great Britain, Germany, Russia:—*Bergen, Paisley, Edinburgh, Birmingham, Kew, Shide, Hamburg, Göttingen, Heidelberg, Jena, Strassburg, Jurjew.*

Mean......$x=78^\circ\ 01'=8667$ *km.*

$t_1=1^h24^m29^s$

$t_1-t_0=12^m29^s=749$ sec.

$v_1=11.57$ *km* per sec.

(viii) Spain, Austro-Hungary, Italy, Burgaria, Formosa:—*San Fernando, Tortosa, Kremsmuenster, Vienna, O'Gyalla, Laibach, Triest, Quarto Castello, Querce, Ximeniano, Cartuja, Zagreb, Pola, Agram, Ischia, Taihoku, Sofia.*

Mean......$x=88^\circ\ 09'=9793$ *km.*

$t_1=1^h25^m31^s$

$t_1-t_0=13^m31^s=811$ sec.

$v_1=12.08$ *km* per sec.

(ix) New Zealand, Turkestan, Java, India:—*Wellington, Christchurch, Tiflis, Taschkent, Batavia, Kodaikanal.*

Mean......$x=108^\circ\ 21'=12038$ *km.*

$t_1=1^h29^m18^s$

$t_1-t_0=17^m18^s=1038$ sec.

$v_1=11.60$ *km* per sec.

Excluding provisionally the three cases of single observations, (i), (ii), and (v) marked with *asterisks*, the six groups (iii). (iv), (vi)—(ix), may be divided into two sets as follows:—

(a)......(iii), (iv)	$x=30^\circ\ 36'$	$v_1=8.19$ *km* per sec.
	$x=35^\circ\ 37'$	$v_1=9.37$,,
Mean	$x=33^\circ\ 7'$	$v_1=8.78$,,
(b)......(vi), (vii), (viii), (ix).	$x=74^\circ\ 43'$	$v_1=11.19$ *km* per sec.
	78 01	11.57
	88 09	12.08
	108 21	12.60

Mean.............. $x=87° 19'$ $v_1=\mathbf{11.61}$ *km* per sec.

Comparing the latter value with the velocity deduced by "difference method" given below, we obtain:—

$$\frac{v_1\,(\text{difference method})}{v_1\,(\text{direct method})}=\frac{13.97}{11.61}=12.03$$

This ratio is to be regarded as holding good, so far as the velocity calculated by "direct method" is concerned, for the distance x of about 70° to 100°.

The relation between the x and v_1 calculated by "direct method," for the six groups (iii), (iv), (vi)......(ix), is graphically shown in Fig. 2, Pl. IX.

"DIFFERENCE METHOD."

In calculating the velocity v_1 by the "difference method", I have taken only the mean values relating to the Groups (iii), (iv), (vi)......(ix). The relation between the time of commencement and the epicentral distance is illustrated in Fig. 1, the dotted curve being drawn with free hand through the mean position. Assuming a linear relation between the time of commencement and the epicentral distance for the limits of the latter quantity given by the groups (iii) and (ix), as indicated by the straight line in Fig. 1, and calculating by the method of Least Squares, we obtain

$$v_1=\mathbf{13.97}\ \textit{km.}\ \text{per sec.}$$

3. *Velocity of Propagation of the 2nd Preliminary Tremor.*

Table III gives, for 21 different stations, the epicentral distance and the time ($=t_2$) of commencement of the 2nd preliminary tremor ; the stations being grouped as follows :—

Group (i). United States and Canada:—*Toronto, Cheltenham, Baltimore.*

Group (ii). Japan :—*Mizusawa*, *Tōkyo*, *Osaka*, *Kobe*.

Group (iii). Central Europe:—*Hamburg*, *Jurjew*, *Göttingen*, *Jena*, *Strassburg*, *San Fernando*, *O'Gyalla*, *Quarto Castello* (Florence), *Zagreb*.

The epicentral distance varied between 79° 38′ and 88° 13′.

Group (iv). *Tiflis*, *Manila*, *Calcutta*, the epicentral distance varying between 99° 16′ and 112° 25′.

Besides these, there are two single stations of Birmingham (x=75° 54′) and Sofia (x=95° 28′).

The relation between the time (t_2) and the distance x, for the four groups (i)—(iv), is illustrated in Fig. 3, (Pl. X).

TABLE III.—SAN FRANCISCO EARTHQUAKE.

Time of Commencement of the 2nd Preliminary Tremor.

Place.	Epicentral Distance $=x$.		Time of Commt. of 2nd Prel. Tremor. $=t_2$.		
			h	m	s
Toronto	32°	59′	13	25	00
Cheltenham	35	44	13	25	04
Baltimore	35	46	13	25	12
(i) **Mean**	**34**	**50**	**13**	**25**	**05**
Mizusawa	70°	50′	13	33	14
Tokyo	73	41	13	34	24
Osaka	77	04	13	34	13
Kobe	77	17	13	34	19
(ii) **Mean**	**74**	**43**	**13**	**34**	**03**
Birmingham	75°	54′	13	35	07
Hamburg	79°	38′	13	34	57
Jurjew	80	05	13	34	43
Göttingen	81	15	13	34	42
Jena	82	21	13	35	09

Place.	Epicentral Distance $=x$.	Time of Commt. of 2nd Prel. Tremor$=t_2$.
Strassburg	82° 49′	13h 35m 20s
San Fernando	85 14	13 35 18
O'Gyalla	87 26	13 36 08
Quarto Castello	88 05	13 37 58
Zagreb	88 13	13 35 32
(iii) **Mean**	**83 54**	**13 35 32**
Tiflis	99° 16′	13 39 13
Manila	100 14	13 37 02
Calcutta	112 25	13 40 48
(iv) **Mean**	**103 58**	**13 39 01**

Calculating the velocity of propagation from the *mean* values given in the above table we obtain the following results.

"DIRECT METHOD."

(i) $x=34° \; 50'=3870$ *km.*

$t_2=1^h25^m05^s$

$t_2-t_0=13^m05^s=785$ sec.

$v_2=4.93$ *km.* per sec.

(ii) $x=74° \; 43'=8301$ *km.*

$t_2=1^h34^m03^s$

$t_2-t_0=22^m03^s=1323$ sec.

$v_2=6.27$ *km.* per sec.

(iii) $x=83° \; 54'=9321$ *km.*

$t_2=1^h35^m32^s$

$t_2-t_0=23^m32^s=1412$ sec.

$v_2=6.60$ *km.* per sec.

(iv) $x=103° \; 58'=11551$ *km.*

$t_2=1^h39^m01^s$

$$t_2 - t_0 = 27^m 01^s = 1621 \text{ sec.}$$
$$v_2 = 7.13 \; km. \text{ per sec.}$$

The above results may be summarized as follows :—

(A) For (i) in which the epicentral distance was 34° 50′, the *direct* velocity v_2 was 4.93 *km.* per sec.

(B) For (ii) and (iii), in which the distance was 74° 43′ to 83° 54′, the mean values are :

$$x = 79° \; 19', \quad v_2 = 6.44 \; km. \text{ per sec.}$$

(C) For (iv), in which the distance was great and equal to 103°58′, the velocity v_2 was 7.13 *km.* per sec.

The relation between the epicentral distance and the velocity v_2, calculated by the "direct method", is graphically shown in Fig. 4, Pl. XI, the curve being, within the limits of 34° 50′ and 103° 58′, approximately straight.

"DIFFERENCE METHOD."

(iv)—(i) ;...... $\delta x = 69° \; 08' = 7680 \; km.$
$$\delta t = 13^m 55^s = 835 \text{ sec.}$$
$$v_2 = 9.20 \; km. \text{ per sec.}$$

(iv)—(ii) ;...... $\delta x = 29° \; 15' = 3249 \; km.$
$$\delta t = 4^m 58^s = 298 \text{ sec.}$$
$$v_2 = 10.90 \; km. \text{ per sec.}$$

(iv)—(iii) ;...... $\delta x = 20° \; 04' = 2227 \; km.$
$$\delta t = 3^m 29^s = 209 \text{ sec.}$$
$$v_2 = 10.66 \; km. \text{ per sec.}$$

(iii)—(i) ; ...... $\delta x = 49° \; 04' = 5450 \; km.$
$$\delta t = 10^m 27^s = 627 \text{ sec.}$$
$$v_2 = 8.69 \; km. \text{ per sec.}$$

(iii)−(ii)......$\delta x = 9° 11' = 1010$ *km.*

$\delta t = 1^m 29^s = 89$ sec.

$v_2 = 11.35$ *km.* per sec.

(ii)−(i) .....$\delta x = 39° 53' = 4430$ *km.*

$\delta t = 8^m 58^s = 538$ sec.

$v_2 = 8.24$ *km.* per sec.

The above results may be summarized as follows :—

(A). For the three combinations, in each of which the shorter distance was 34° 50′, the velocity v_2 was small, namely,

$v_2 = 9.20$ *km.* per sec.
8.69
8.24

Mean .....**8.71** *km.* per sec.

(B). For the three remaining combinations, in each of which the shorter distance was over 74° 43′, the velocity was greater :—

$v_2 = 10.90$ *km.* per sec.
10.66
11.35

Mean......**10.97** *km.* per sec.

Mean value of v_2. Taking the four groups (i)......(iv), Table III, and assuming a linear equation between the epicentral distance and the time of commencement of the 2nd preliminary tremor, we obtain by method of Least Squares, the following mean value :—

$v_2 = $ **9.02** *km.* per sec.

Comparing this with the value of the velocity v_1 given in §2, we see that

$$\frac{v_1}{v_2} = \frac{13.97}{9.02} = 1.549\,;$$

this ratio relating to the velocities between the distance limits of about 30° and 100°

4. *Duration of the 1st Preliminary Tremor.*

Table IV gives the duration (y_1) of the 1st preliminary tremor at the different stations, arranged according to the epicentral distance (x).

TABLE IV.—SAN FRANCISCO EARTHQUAKE.

Duration of the 1st Preliminary Tremor.

Place.	Epicentral Distance=x	Duration of 1st Prel. Tremor=y_1
Tacubaya	27° 57′	4m 53s
Ottawa	35° 27′	5 31
Washington	35° 32′	5 26
Cheltenham	35° 44′	5 38
Mean	**35° 34′**	**5 32**
Vieques (Porto Rico)	53° 38′	7 38
Mizusawa	70° 50′	9 07
Tokyo	73° 41′	9 49
Osaka	77° 04′	9 49
Kobe	77° 17′	9 56
Mean	**74° 43′**	**9 40**
Paisley	72° 27′	10 12
Birmingham	75° 54′	10 04
Kew	77° 17′	8 12
Hamburg	75° 54′	10 25
Jurjew	80° 05′	10 04
Göttingen	81° 15′	10 08
Jena	82° 21′	10 35
Strassburg	82° 49′	10 24
Mean	**78° 30′**	**10 01**
Ximeniano	88° 08′	10 57
Querce	88° 08′	10 42
Quarto Castello	88° 05′	10 56

TABLE IV.—*Continued.*

Place.	Epicentral Distance $=x$.	Duration of 1st Prel. Tremor $=y_1$.
Ischia	91° 45′	11m 27s
Mean	**89° 02′**	**11 01**
Tiflis	99° 16′	11 56
Manila	100° 14′	14 20
Mean	**99° 45′**	**13 08**

According to Table IV the mean values of the epicentral distance (x) and the corresponding duration (y_1) of the 1st preliminary tremor are as follows: —

x=27° 57′ ;	y_1=4m 53s
35° 34′	5 32
53° 38′	7 38
74° 43′	9 40
78° 30′	10 01
89° 02	11 01
99° 45′	13 08

The relation of x and y_1, as illustrated in Fig. 5, Pl. XII, is nearly linear. Assuming, therefore, an equation of the 1st degree between these two quantities, and determining the constants by the method of Least Squares, we obtain the following formula: —

$$x = 16.79\, y_1 - 1618\ km.$$

The deduction of this equation, whose application is limited between x=about 30° and 100°, differ from that of similar equations hitherto given in that the data utilized in the calculation relate all to one and the same earthquake, and not to the observations at one given station of different earthquakes.

5. *Milne Horizontal Pendulum Seismograms obtained at San Fernando and Wellington.*

In Figs 6 and 7, Pl. XIII, I reproduce the Milne Horizontal Pendulum seismograms obtained at San Fernando (Spain) and Wellington (New Zealand); these records having been selected on account of the clearness with which they indicate the W_2 waves, or the earthquake vibrations propagated along the major arcs of the earth. The explanation to the Wellington diagram is that given by Mr. G. Hogben.

In each diagram, the letter *A* marks the probable commencement of the 3rd phase of the principal portion.

The portion marked W_3 in the San Fernando diagram may correspond to the repetition of the earthquake motion propagated first along the minor arc, which came back after making one complete circuit of the earth.*

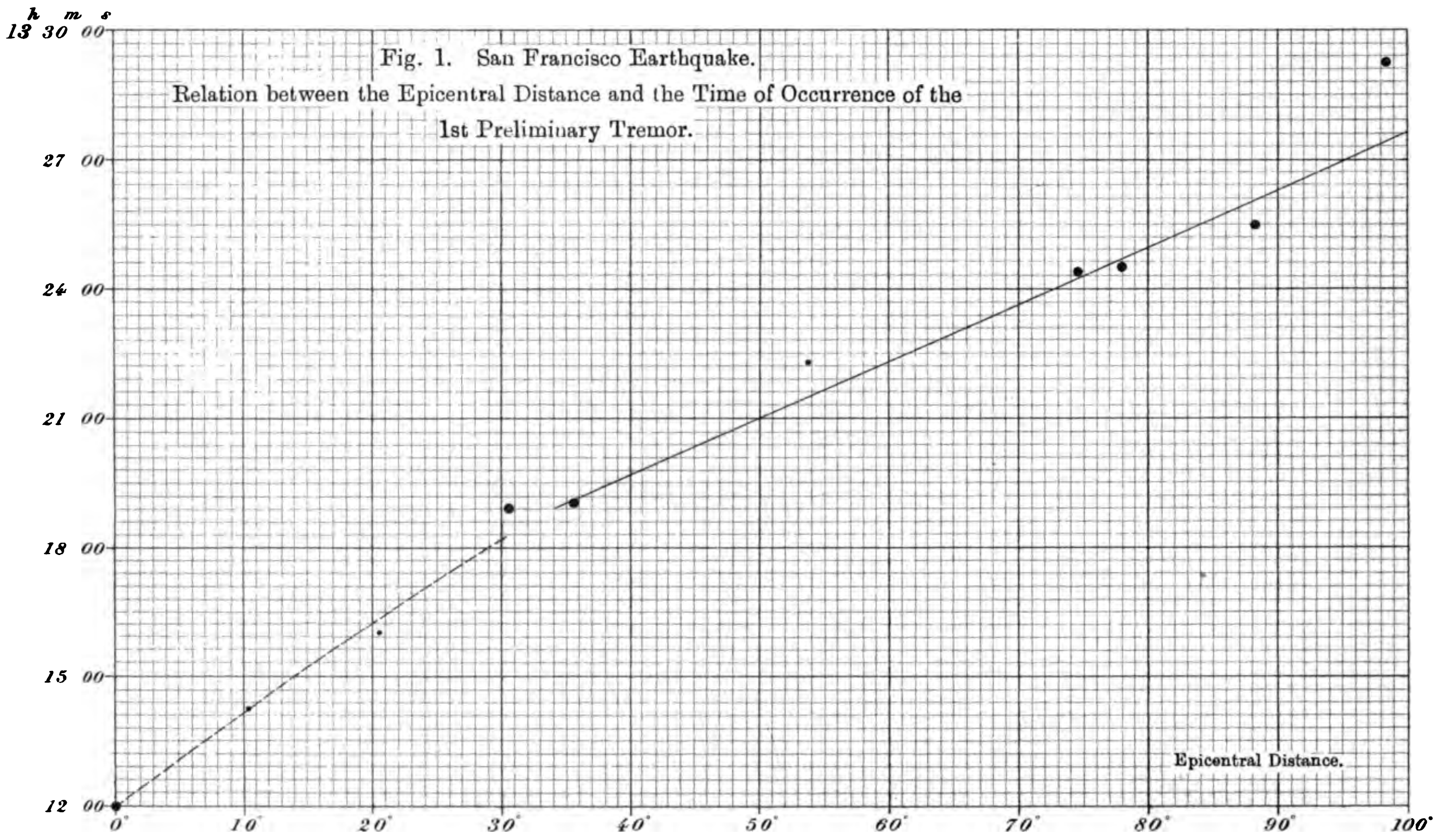
The epicentral distances of San Fernando and Wellington are respectively 85° 14′ and 97° 40′, the former station being 12° 26′ or 1381 km nearer to the origin of the earthquake. Accordingly the W_2 motion occurred some minutes earlier in the Wellington record than in the San Fernando one.

San Fernando Seismogram. Commencement of the earthquake $=13^h\ 25^m\ 06^s$. The principal portion began approximately at $13^h\ 49^m\ 30^s$. The first maximum motion, probably corresponding to the 3rd phase of the principal portion, occurred at $13^h\ 57^m\ 18^s$; the 2nd maximum occurring at $14^h\ 03^m\ 05^s$.

The W_2 motion began at $15^h\ 13^m$, the 3rd phase of its principal portion commencing at $15^h\ 32^m\ 42^s$. The motion remained active till $15^h\ 46^m$.

Wellington Seismogram. Commencement of the earthquake

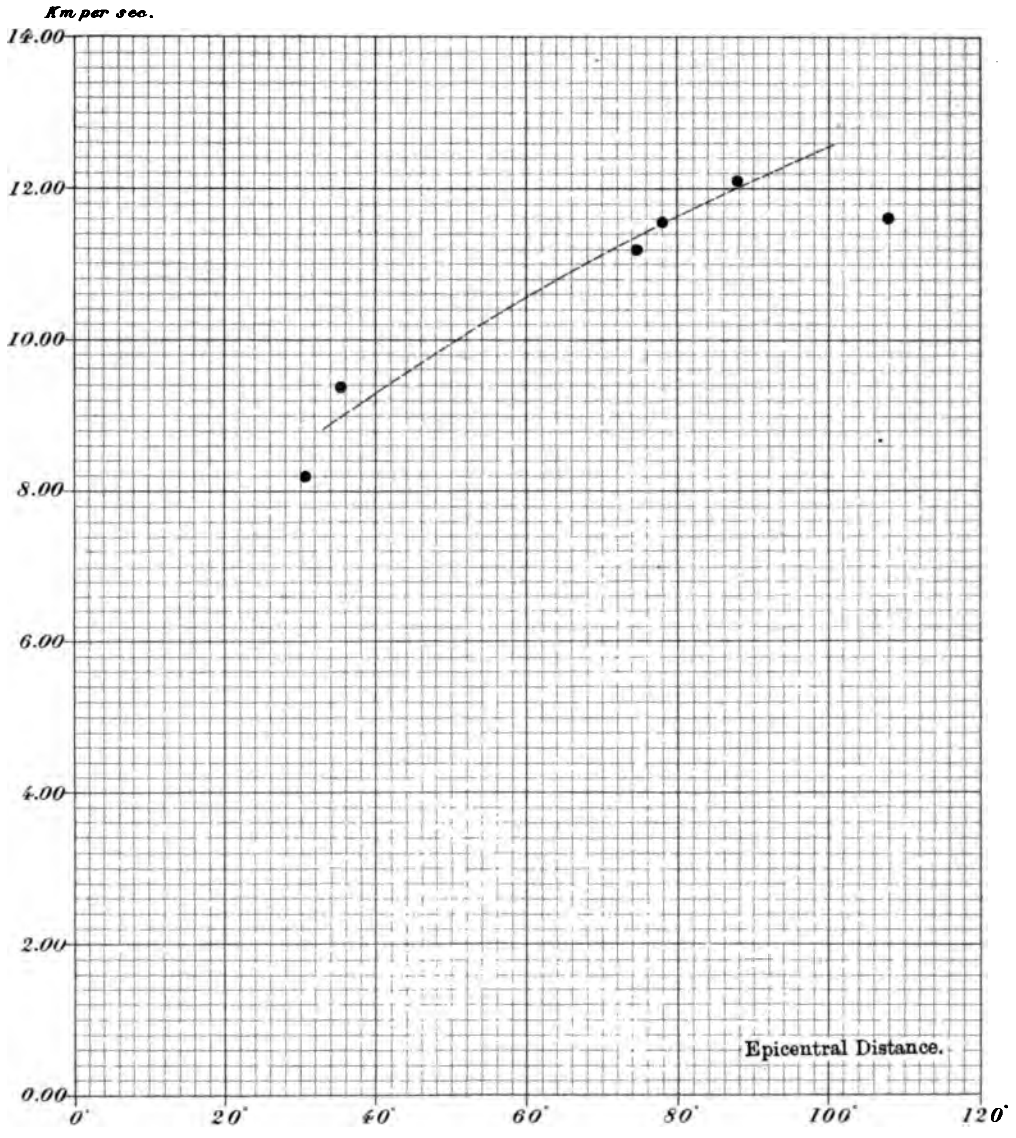
* Mr. Hogben identifies the earthquake movements for the successive repetitions.



A large dot relates to a mean group value, while a small dot relates to a single value.

Fig. 2. San Francisco Earthquake.

Relation between the Epicentral Distance and the Velocity v_1, " directly " calculated.



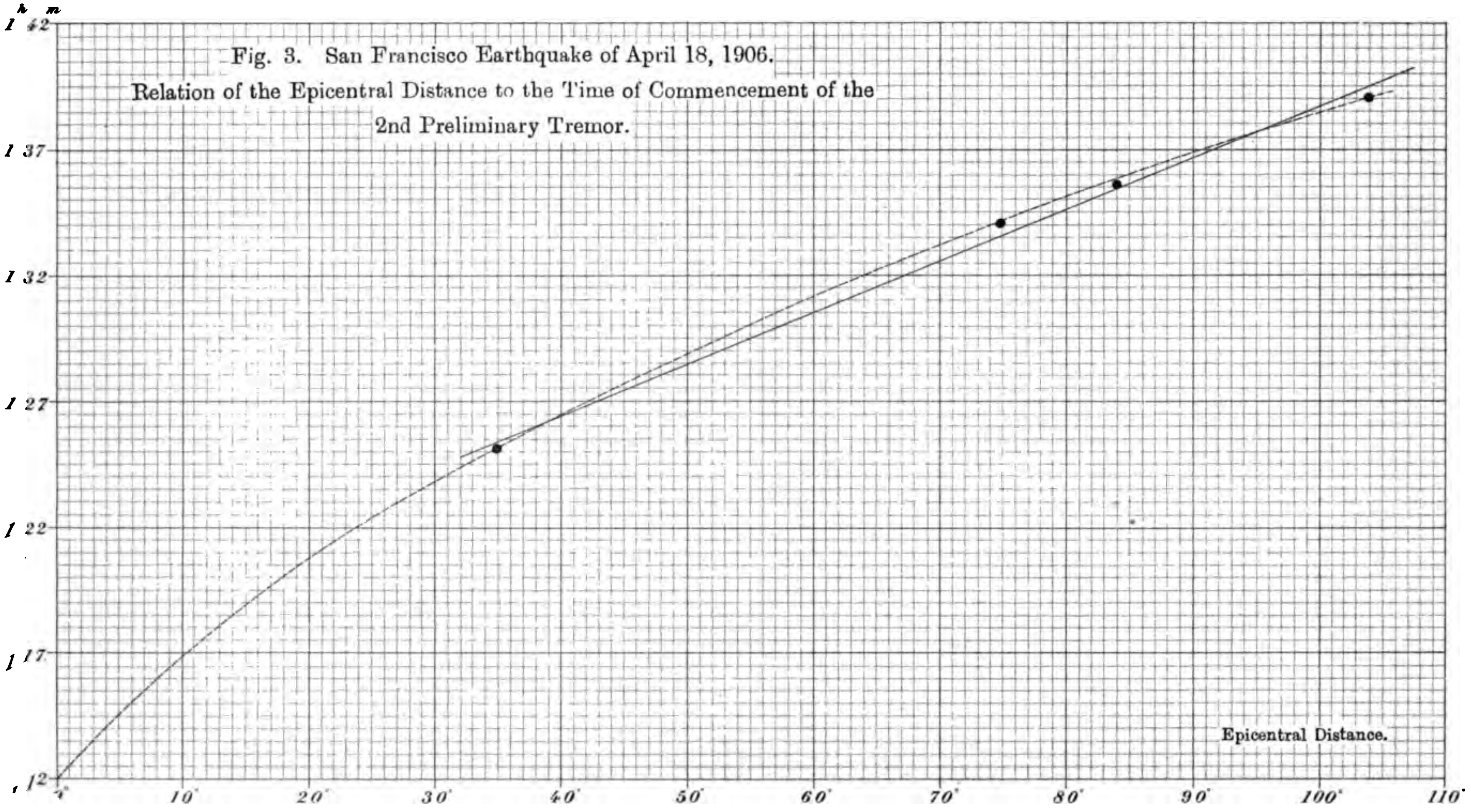
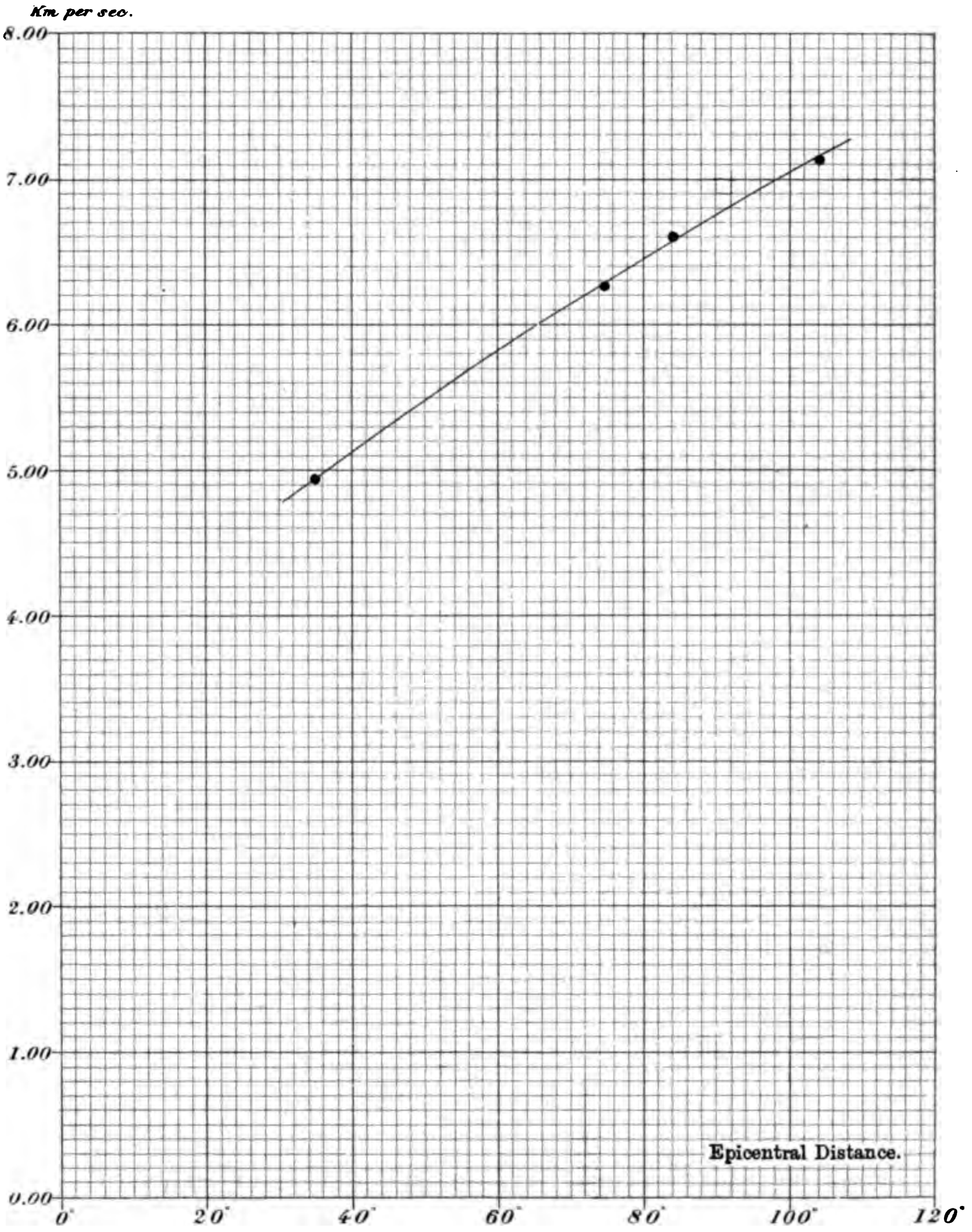


Fig. 3. San Francisco Earthquake of April 18, 1906.
Relation of the Epicentral Distance to the Time of Commencement of the
2nd Preliminary Tremor.
h m
1 42
1 37
1 32
1 27
1 22
1 17
1 12
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
Epicentral Distance.

Fig. 4. San Francisco Earthquake.
Relation between the Epicentral Distance and the Velocity v_2, " directly " calculated.



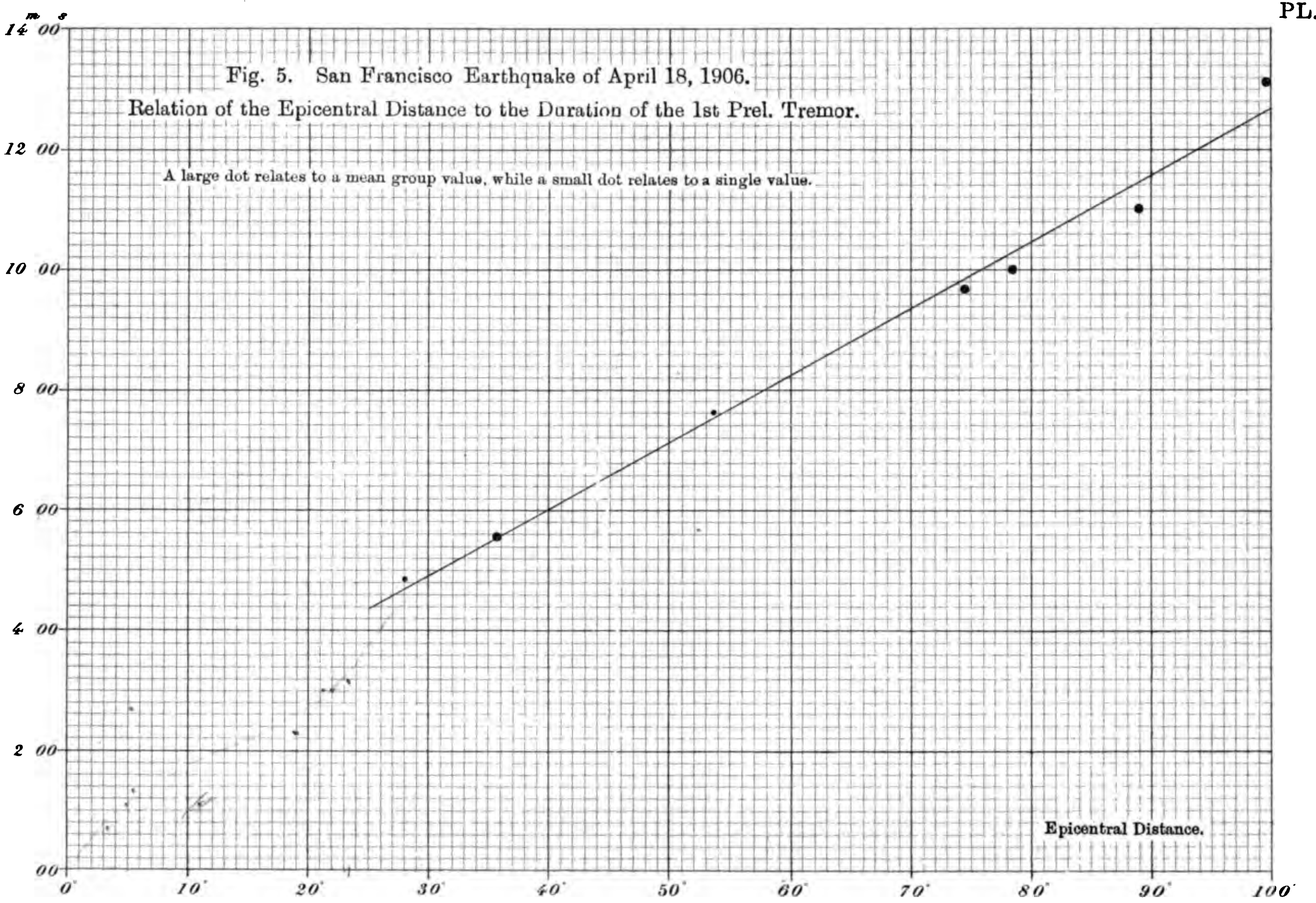
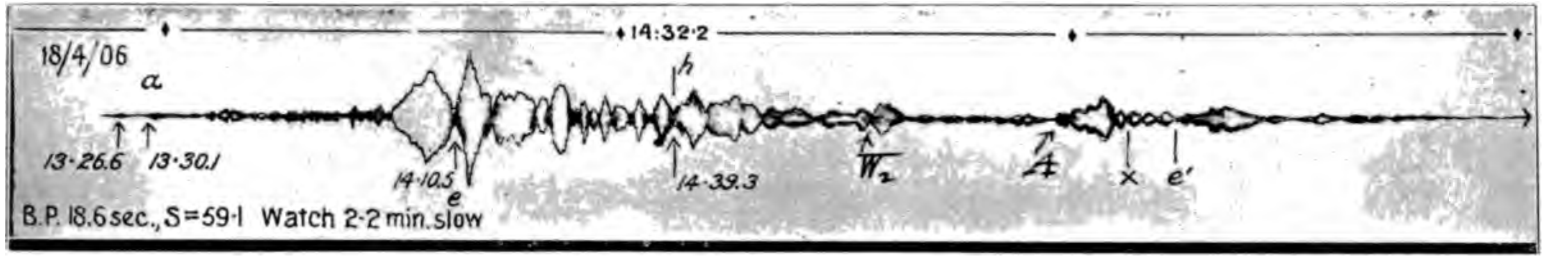


Fig. 5. San Francisco Earthquake of April 18, 1906.
Relation of the Epicentral Distance to the Duration of the 1st Prel. Tremor.
A large dot relates to a mean group value, while a small dot relates to a single value.
14 00 m s
12 00
10 00
8 00
6 00
4 00
2 00
00
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
Epicentral Distance.

SAN FRANCISCO EARTHQUAKE.—RECORD OF MILNE HORIZONTAL SEISMOGRAPH AT WELLINGTON, NEW ZEALAND.

OBSERVER—G. HOGBEN, M.A. [Time, Greenwich mean civil time.]

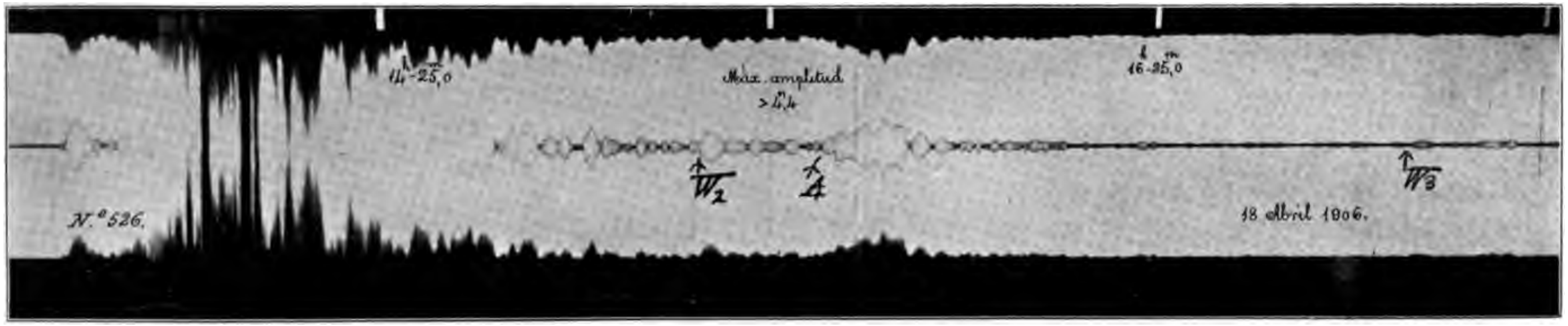
Fig. 6.



The letters denote the waves of the different phases according to Omori's classification: *a*, first phase ("preliminary tremors"); *e*, fifth phase ("long waves"); *e'*, ditto, along the major arc; *h*, eighth phase (probably "transverse waves"); *h'*, ditto, along the major arc. The "repeats" (after successive circuits of the earth) bear the same letters.

SAN FRANCISCO EARTHQUAKE.—RECORD OF MILNE HORIZONTAL PENDULUM SEISMOGRAPH AT THE MARINE OBSERVATORY OF SAN FERNANDO.

7.



$=13^h\ 26^m\ 36^s$. The 1st maximum motion, approximately corresponding to the commencement of the principal portion, occurred at $14^h\ 02^m\ 00^s$. The 2nd and largest maximum, which probably corresponded to the 3rd phase of the principal portion, occurring at $14^h\ 10^m\ 30^s$. The 6th phase of the same portion, probably the "transverse" vibration, occurred at $14^h\ 39^m\ 18^s$.

The W_2 motion began at $15^h\ 05^m\ 18^s$; the 1st maximum, which probably corresponded to the commencement of the 3rd phase of the principal portion, occurring at $15^h\ 30^m\ 18^s$. The 2nd maximum occurred at $15^h\ 47^m\ 06^s$.

Comparing the W_1, or the earthquake proper with the W_2 motion, we obtain the following approximate values of the velocities.

Place	Commencement of Princ. Portion.	Commencement of 3rd Phase, Princ. Portion.
San Fernando	4.2 km./sec.	3.7 km./sec.
Wellington	4.8	3.8

These are to be regarded as only gross approximations.

6. The foregoing paragraphs constitute only the preliminary notes on the seismographic observations of the San Francisco earthquake. A full discussion of the transit velocities corresponding to the different phases of the earthquake motion, and the results of the analysis of the seismograms will be given in a future number of the *Publications of the Earthquake Investigation Committee.*

Note on the Transit Velocities of the Guatemala Earthquake of April 19, 1902.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

In the *Proceedings of the Royal Society of London*, Vol. A 76, 1905, Mr. R. D. Oldham* gives an important discussion of the transit velocities of the Guatemala earthquake of April 19, 1902. As, however, Mr. Oldham confines himself to the velocity calculation by the "direct method," I shall here try the calculation by the "difference method" of the velocity of propagation of the 1st preliminary tremor.

The following table, which gives for the different stations the epicentral distance and the time of occurrence and the duration of the 1st preliminary tremor, is taken from Mr. Oldham's paper.

GUATEMALA EARTHQUAKE OF APRIL 19, 1902.

Station.	Epicentral Distance.	Time of occurrence. (G. M. T.)	Duration of 1st Prel. Tremor.
		min.	min.
Baltimore	27°.8	2^h 30.1	5.5
Toronto	30.8	30.5	5.0
Victoria, B.C.	43.0	31.3	5.9
Cordova, Arg.	52.7	32.1	7.0
Mean	**38.6**	**31.0**	**5.9**
Edinburgh	77.0	36.0	9.5
Bidston (Liverpool)	77.4	35.0	—
San Fernando	77.6	34.8	8.5

* R. D. Oldham: "The Rate of Transmission of the Guatemala Earthquake, April 19, 1902."

GUATEMALA EARTHQUAKE.—*Continued.*

Station.	Epicentral Distance.	Time of occurrence. (G. M. T.)	Duration of 1st Prel. Tremor.
	°	h min.	min.
Shide (I. of Wight)	78.8	2 35.5	11.4
Kew	79.3	36.2	9.6
Mean	**78.0**	**35.5**	**9.8**
Uccle	82.3	36.0	10.4
Hamburg	84.9	36.3	10.3
Strassburg	85.0	36.2	—
Padua	88.6	36.6	10.6
Florence.....................	88.7	36.6	10.3
Triest	90.2	36.8	12.1
Rome	90.2	37.6	12.7
Quarto Castello............	90.4	36.8	10.5
Rocca di papa..............	90.4	37.0	10.3
Jurjew	91.4	36.8	9.9
Ischia	91.7	37.0	10.6
Catania	93.6	36.7	—
Mean	**89.0**	**36.7**	**10.8**
Nicolajew	100.3	37.0	—
Wellington..................	102.5	38.0	9.0
Christchurch	104.5	37.2	10.8
Mean	**102.4**	**37.4**	**9.9**
Tokyo........................	110.4	38.8	15.7
Tiflis	110.7	38.2	18.3
Irkutsk	111.9	42.9	16.2
Cape Town...................	113.9	38.4	13.2
Mean	**111.7**	**39.6**	**15.9**
Taschkent	121.3	40.2	9.5
Calcutta	142.9	44.0	—
Bombay	144.1	43.5	22.1
Perth, W. A...............	149.8	43.8	18.2
Kodaikanal	152.9	—	20.4
Batavia	160.4	43.7	24.3
Mean	**{149.3* 151.8**	**43.8**	**21.3**

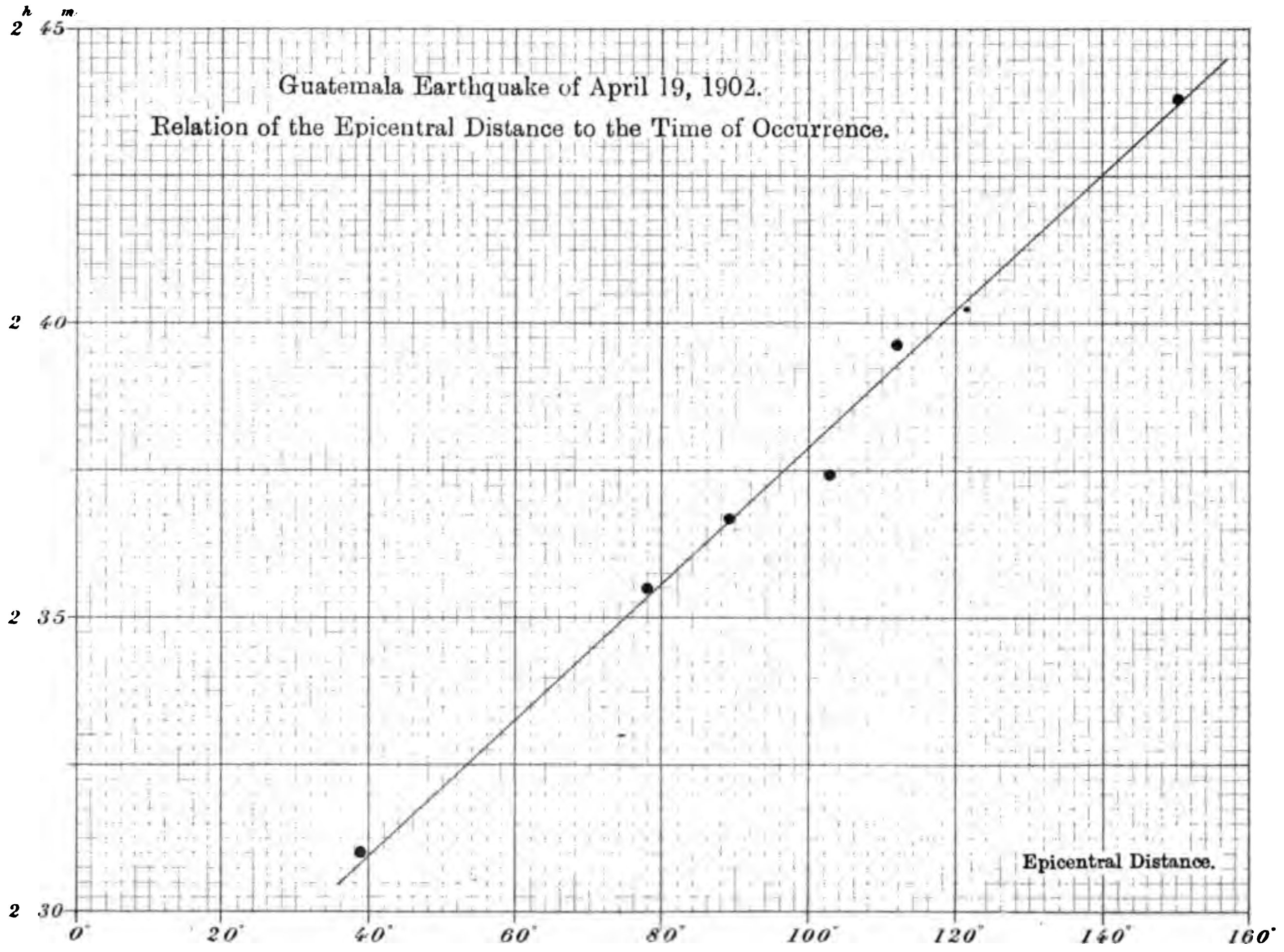
* 149.3 is the mean distance obtained by omitting Kodaikanal, and 151.8 that obtained by omitting Calcutta. These two values are to be used respectively for the time of occurrence and the duration of the 1st preliminary tremor.

I have divided the 34 stations contained in the preceding table into 7 groups, the relation between the mean values of the epicentral distance and the time of occurrence being illustrated in the accompanying figure (Pl. XIV). From the latter it will be seen that, within the limits of the distance under consideration, the time of earthquake occurrence increased linearly with the distance. Assuming, therefore, an equation of the 1st degree between the time and the distance, and calculating by the method of Least Squares, we obtain

$$v_1 = 16.02 \ km. \text{ per sec.}^*$$

This value of v_1 is 2 *km.* greater than that found for the San Francisco earthquake, as given in the preceding article.

* The value of v_1 previously obtained for this earthquake by Dr. A. Imamura was 15.6 *km.* per sec.



The small dot refers to Taschkent; all the large dots refer to group means.

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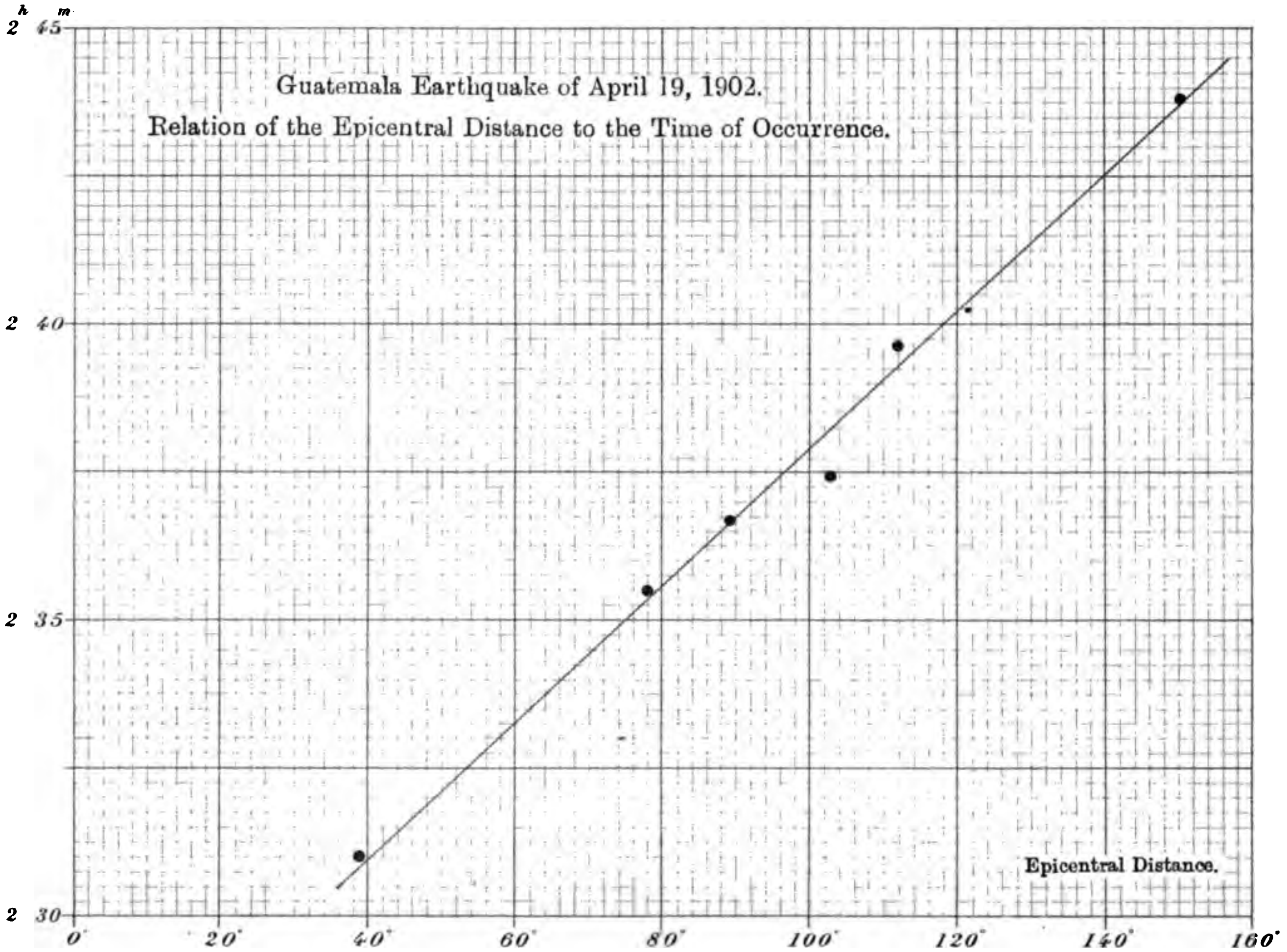


The small dot refers to Taschkent; all the large dots refer to group means.

The Calabrian Earthquake of Sept. 8, 1905, observed in Tokyo.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

1. Pl. XV gives the EW, NS, and vertical components of motion due to the disastrous Calabrian earthquake of Sept. 8, 1905, observed in the University compound, (Hongo), Tokyo; the magnifying ratios in the three diagrams being respectively 15, 20, and 12. The details of construction of the two horizontal component instruments,* which are nearly alike to one another, are as follows:—

Vertical distance between the points of suspension and of support=2 metres.

Effective length of the strut, or the horizontal distance between the point of support and the steady axis=1 metre.

Weight of the heavy bob=.....................{17.4 kg. (EW). 46.0 kg. (NS).

Natural Oscillation Period ....{61.5 sec. (EW). 48.5 sec. (NS).

The vertical instrument, which is one of Gray-Ewing type, has the following specifications :

Length of the vertical spiral springs=1.2 metre.

Horizontal distance between the centre of the steady mass and the pivot=1.2 metre.

Weight of the heavy bob=9 kg.

Natural Oscillation period=6.0 sec.

The time of commencement of the earthquake motion was 1^h 56^m 09^s (G.M.T.). In the following descriptions of the seismograms, T and $2a$ denote respectively the complete period and the double amplitude of motion.

* These are the long-period horizontal pendulums described in the *Publications*, No. 5, with some changes in the weight of the steady mass and the multiplication ratios.

2. *EW Component.* Total duration=3 hours. The commencement was very small, and slightly uncertain.

1st Preliminary Tremor. Duration=10^m 25^s. For the first 2^m 0^s, the motion was very small. The subsequent motion was larger and nearly uniform:—T=7.7 sec., max. $2a$=3.3 mm, there being also traces of small vibrations.

2nd Preliminary Tremor. Duration=11^m 49^s. The motion was greater during the first 6^m 20^s than during the rest of this phase:—

$$\begin{cases} T= \ \ 6.4 \text{ sec., max. } 2a=0.1 \text{ mm.} \\ \ \ \ \ \ \ \ \ 8.3 \ \ ,, \ \text{, small.} \\ \ \ \ \ \ \ 11.6 \ \ ,, \ , \ \ ,, \end{cases}$$

Principal Portion. [1st and 2nd phases.] Duration=10^m 43^s. During the first 5^m 48^s, the motion was small:—T=21.2 sec., max. $2a$=0.6 mm., there being also small vibrations of T=8.7 and 6.4 sec. For the next 2^m 25^s, there were 3 small slow vibrations:—T=48.3 sec., max. $2a$=0.05 mm, superposed by small vibrations of T=8.5 sec. For the remaining 2^m 29^s, there were 4 larger and nearly equal vibrations:—T=37.3 sec., max. $2a$=0.13 mm; there being also some small vibrations. [3rd phase.] Duration=9^m 39^s. During the first 2^m 8^s, the motion consisted of 4½ regular vibrations:—T=28.5 sec., the 4th having the max. $2a$ of 0.35 mm. For the next 2^m 38^s, the vibrations were smaller and quicker:—T=21.1 sec., max. $2a$=0.24 mm. For the remaining 4^m 57^s, the vibrations became again quicker:—T=14.5 sec., the two max. $2a$'s of 0.45 and 0.50 mm. occurring respectively 5^m 39^s and 8^m 54^s after the commencement of this phase. There were also some traces of vibrations of T=28.8 sec. [4th phase]. During the first 5^m 25^s, the motion was large :—T=17.7 sec., max. $2a$=0.21 mm ; T=11.8 sec., max. $2a$=0.20 mm. During the remaining 10^m 53^s of this phase, the motion was

smaller and nearly uniform:—T=11.1 sec., max. $2a$=0.12 mm; T=16.9 sec., max. $2a$=0.08 mm. [5th, etc. phases]. The motion was much smaller. Toward the end, T=13.9 sec.

The W_2 vibrations, or the earthquake movements propagated along the major arc of the earth, appeared at 3^h 47^m 10^s (G.M.T.)

3. *NS Component.* The commencement was very small and slightly indistinct.

1st Preliminary Tremor. Duration=about 10^m 57^s. For the first 1^m, the motion was very small. The subsequent motion was nearly uniform :—T=6.0 sec., max. $2a$=0.03 mm, mixed with some vibrations of T=11.3 sec.

2nd Preliminary Tremor. Duration=9^m 44^s. The motion was greater near the commencement :—T=7.0 sec., max $2a$=0.08 mm; T=10.3 sec., max. $2a$=0.12 mm.

Principal Portion. [1st and 2nd phase.] Duration=11^m 30^s. During the first 9^m 44^s, the motion was nearly constant:—

$$\begin{cases} T=14.9 \text{ sec., max. } 2a=0.06 \text{ mm;} \\ \;,,= 8.0 \quad ,\; ,, \quad =0.05 \;,, \;; \\ \;,,= 4.0 \quad , \text{ small.} \end{cases}$$

During the remaining 1^m 47^s, there were 2 and half well-defined vibrations:—T=42.8 sec., max. $2a$=0.1 mm. [3rd phase.] Duration=15^m 18^s. During the first 1^m 29^s, there were 2 and half well-defined and nearly equal vibrations:—T=35.7 sec., max. $2a$=0.22 mm. For the next 2^m 14^s, the vibrations became quicker:—T=26.8 sec., max. $2a$=0.33 mm. For the next 1^m 35^s, the motion was smaller:—T=19.0 sec., max. $2a$=0.25 mm. For the next 1^m 11^s, there were 2 slow small vibrations:—period=35.5 sec., max. $2a$=0.09 mm, superposed with small movements of T=10.1 sec. Thereafter the motion became much quicker and active, the vibrations during the next 2^m 31^s being T=15.1 sec.,

max. $2a$=0.35 mm, mixed with slower vibrations of T=30.2 sec., max. $2a$=0.40 mm. For the next 1^m 42^s:—T=25.5 sec, max. $2a$=0.33 mm. For the next 1^m 51^s, the motion became again quicker:—T=13.9 sec., max. $2a$=0.13 mm. During the remaining 9^m 28^s, the period remained nearly constant:—T=16.2 sec., max. $2a$=0.43 mm, mixed with some small vibrations of T=10.3 sec. [4th, etc. phases.] During the first 8^m 20^s:—T=11.3 sec., max. $2a$=0.08 mm; T=19.7 sec., max. $2a$=0.09 mm.

End Portion. The vibrations had a T of 13.2 sec., there being also some vibrations of T=17.1 sec.

The W_2 vibrations which appeared at 4^h 06^m 26^s (G.M.T.), were small but well defined:—T=18.5 sec., max. $2a$=small.

4. *Vertical Component.* The motion began with small quick vibrations. At 2^h 32^m 57^s (G.M.T.), there appeared small slow vibrations continuing for about 10 min. 7^m 20^s later on the movements became more distinct :—T=15.2 sec., max. $2a$= 0.03 mm.

Appendix. The observations of the Calabrian earthquake at Osaka and Mizusawa were as follows:—

***Osaka* (*EW*).**

Total Duration=1^h 24^m. Time of commencement=1^h 56^m 31^s.

1st Prel. Trem.	Duration=10^m15^s;	T=6.6 sec.;	max. $2a$=0.2 mm.
2nd „ „	„ =11 10;	„=6.7 „;	„ „ =0.7 „

Principal Portion:—

1st and 2nd phases.	Dur.=7^m10^s;	T=20.0 sec.;	max. $2a$=0.4 mm.
3rd phase.	„ =8 25;	„ =21.9 „;	„ =0.5 „
4th „	„ =8 30;	„ =17.1 „;	„ =0.4 „
5th „	„ =9 00;	„ =12.7 „;	„ =0.1 „
6th „	„ =8 10;	„ =15.4 „;	„ =0.5 „

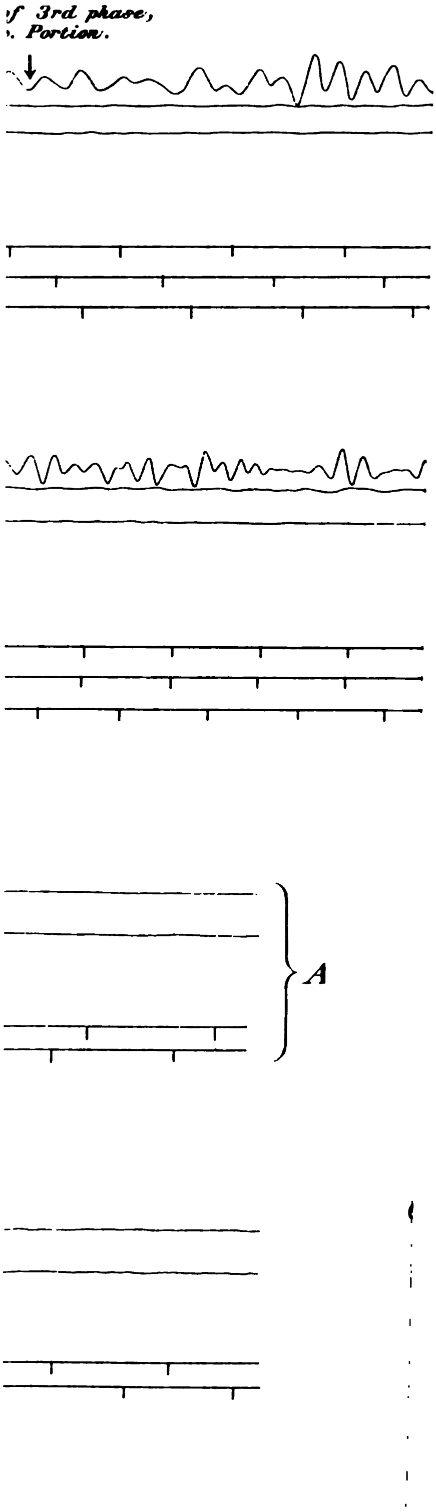
7th phase.	Dur. = 7 45 ; T = 13.8 sec.; max. $2a$ = 0.2 mm.
End Portion.	„ = 14.4 „ ; „

Mizusawa.

Time of commencement = 1^h 56^m 12^s.

$\begin{cases}\text{Max. } 2a = 0.03 \text{ mm. (EW Component),} \\ \quad „ \quad = 0.09 \quad „ \quad \text{(NS} \qquad „ \qquad \text{).}\end{cases}$

The instruments at Osaka and Mizusawa are horizontal pendulums of portable form, the natural oscillation perlod at Osaka being about 28 sec.



...f 3rd phase,
... Portion.
A

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Preliminary Note on the Formosa Earthquake of March 17, 1906.

By

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1. ***Introduction.*** The Island of Formosa is preëminently an earthquake country and has been visited within the last 2 years between April 1904 and April 1906, by no less than 4 destructive shocks. From the time of Teiseikō, a Chinese general who occupied the island in the middle of the 17th century at the downfall of the Min dynasty, there were, up to 1906, eighteen severe earthquakes, as follows.

NO.	DATE.	LOCALITY.	REMARKS.
1	Jan. 21, 1655.	Tainan.	
2	———, 1660.	”	
3	Nov. 1, 1720.	”	
4	Jan. 5, 1721.	”	Many people killed; mud and water ejected. Shocks continued for more than 10 days.
5	Jan. 27, 1736.	Tainan, Kagi, Shōka...	Many people killed. The weather was fine.
6	Dec. —, 1776.	Kagi.....................	Great many people killed.
7	July 20, 1792.	Kagi.....................	Fires broke out after the earthquake, more than 100 people killed.
8	July —, 1815.	Giran.	
	Oct. —, 1815.	Tansui.	
10	———, 1816.	Giran	Houses destroyed. The ground was cracked, and in some places convulsed.
11	Nov. —, 1840.	Toroku.....................	Houses destroyed. Landslips took place.

NO.	DATE.	LOCALITY.	REMARKS.
12	June 6, 1862.	Tainan, Kagi, Shōka...	This was a very great earthquake, and in Kagi more than 1000 persons were killed. The mount Daisen was much cracked.
13	Dec. 18, 1867.	Keelung	Great destruction in the harbour of Keelung, where several hundreds of people were drowned by the sea waves. Enormous landslips took place.
14	June 7, 1901.	Giran.	
15	April 24, 1904.	Toroku to Banshoryō...	3 persons killed, 13 wounded.
16	Nov. 6, 1904.	Toroku, Kagi, Ensuikō.	145 „ „ , 148 „ .
17	March 17, 1906.	Kagi, Toroku............	1266 „ „ , 2476 „ .
18	April 14, 1906.	Kagi, Ensuikō...........	15 „ „ , 87 „ .

Of the 18 earthquakes given in the above table, 13 originated in the south-western part of the island, namely, in the Prefectures of Toroku, Kagi, Ensuikō, and Tainan. The 5 other earthquakes shook the north-eastern part of the island, their origins being submarine.

In the *Reports* (Japanese) *of the Imperial Earthquake Investigation Committee*, No. 54, the present author, who visited Formosa in Nov. 1904, has given a full account of the two destructive earthquakes of that year, together with the results of the seismographical measurements made at the different observatories in the island.

EARTHQUAKE OF MARCH 17, 1906.

2. ***Damage.*** The earthquake of March 17, 1906, at $6^h\ 42^m\ 30^s$ A.M.,* was the severest which shook Formosa in recent times, being even more destructive than the well-known great shock of June 6, 1862. The numbers of the houses damaged and the casualties were as follows : —

* Given in 2nd Normal Japan Time, or that of longitude 120° E of Greenwich.

Number of dwelling houses totally destroyed..........	7,284
,, ,, ,, ,, partially ,, ...	30,021
,, ,, persons killed....................................	1,266
,, ,, ,, wounded....................................	2,476

As far as the loss of life is concerned, this earthquake was, among the recent Japan shocks, only second to the great Mino-Owari catastrophe of 1891.

Immediately after the earthquake of March 17, 1906, I proceeded again to Formosa and was able, amongst other things, to compare the seismic effects on this occasion with those in Nov. 1904. One specially interesting feature in this earthquake was the formation of remarkable faults, which are described in § 4.

The heavy amount of the casualties was, in a great measure, due to the weakness of the native dwelling houses, which mostly have no capacity of resisting earthquake shocks, being built of *dokaku*, or sun-dried mud blocks of dimensions $22 \times 33 \times 9\frac{1}{2}$cm., loosely cemented with a mortar of mud, at best mixed with a small quantity of lime. The consequence of such a bad method of construction, joined to the heaviness of the roof, is that the native houses are, at the occurrence of a violent shock, at once shattered to pieces, leaving little time for the people to escape. The easiness with which the *dokaku* houses are overthrown may be seen from the fact that the town of Dabyō was almost entirely levelled to the ground with the exception of the Sub-Prefectural Office, a brick one-story building with a two-story tower, which suffered no severe damage except some cracks in walls and the falling down of part of the roof tiles. Framed timber structures resist earthquake shocks infinitely better than the *dokaku* houses, but they are generally exposed, when old, to a great danger from the ravages of white ants, which literally eat up the wood.

Fig. 9 shows the ruined condition of a native temple, Maso-byō, in the town of Shinkō, the destruction of the building being very complete. Fig. 8 gives a view after the earthquake of the Sub-Prefectural Office in the same town, a wooden structure with plastered walls, which was very severely damaged, due mainly to the vibration of the front tower, but was not overthrown to the ground.

3. *Isoseismals.* The earthquake was felt all over the Island, the three isoseismal lines in Fig. 1 (Pl. XVI) giving approximate boundaries of the areas defined as follows :—

(1) *Area of violent motion,* in which the damage was considerable.

(2) *Area of severe motion,* in which occurred more or less such damage as landslips, cracks of the ground, partial or total destruction of a few buildings, etc.

(3) *Area of moderate motion,* in which the shock was moderately strong, so that some furnitures were overthrown, pendulum clocks were stopped, etc.

Different from usual cases of seismic disturbances in Formosa the longer axes of the isoseismal areas, especially, Nos. 1 and 2, are not parallel to the length of the Island, evidently due to the fact that the fault and the epifocal zone was oblique to the latter.

The area (1) of violent motion was about 50^{km} in length, from the vicinity of the town of Baishikō on the east to the city of Shinkō on the west, and about 30^{km} in width from the vicinity of the city of Kagi on the south to that of the village of Tarimu on the north. From the limited extension of the area of the severe motion, it may be inferred at once that the earthquake centre was not deep below the surface, as was in fact indicated by the formation of the faults.

4. *Faults.* (See Pl. XVII.) The main fault line is most

markedly shown at its eastern end, where it crosses the road leading from the town of Taihorin to Baishikō, at about 1^{km} from the latter town. The fault runs here in the direction of N 75° E and S 75° W, the south side being depressed 6 feet and relatively sheared 6 feet westwards. Fig. 5 gives a general view of the fault, the left-hand (south) side being depressed in such a way that it curves down toward the plane of discontinuity. Fig. 4 shows how the road was cut off and displaced at its intersection with the fault. The small village of Bishō, under which the fault passed, was completely destroyed. The western continuation of the fault passes across a hill spur and appears again to the south of the village of Kaigenkō, at about 1^{km} from Bishō. The fault then runs in a mean direction of N 75° E to S 75° W and crosses the river Sanjōkei, at 5^{km} from Kaigenkō and about 1^{km} to the SW of the village of Maenryō, producing a 4 feet dislocation of the river bed. Then it becomes nearly SW in direction and passes between the villages of Tensanshikiaku and Kasanshikiaku, meeting finally to the south of the latter the branch fault of Chinsekiryō. This second fault starts at about half a kilometre to the west of the village last named, on the top of a gently sloping hill of hard clay, and manifested itself first as a remarkable deep crack of 2 feet width, the depth ascertained with a bamboo stick being 11 feet. (See Fig. 6.) This fault is nearly in the E W direction and its western continuation passes through cultivated grounds, cutting at right angles a series of potato field ridges, which latter suffered a relative horizontal displacement amounting to the interval between two successive ridges, so that each of the latter became, after the earthquake, contiguous to its former neighbour. The fault then runs through the puddy fields, to the north of the village of Tōseiko, finally reaching the city of Dabyō, beyond which the disturbance

of the ground ceases to be apparent. The railroad, which runs in an N–S direction was much damaged between Dabyō and Kagi, especially at its intersection with the fault, 8 rails being considerably bent and a number of rail joints torn apart. The length of the main, or Baishikō, fault is about 11^{km}, while that of the branch, or Chinsekiryō, fault is a little over 4^{km}, the whole length between the Dabyō and Baishiko ends being $13\frac{1}{2}^{km}$.

As stated before, at the eastern extremity of the main fault the south-side was depressed and sheared westwards. But, along the whole rest of the fault the relation was reversed, and the depression was invariably on the north (or NNW) side, the shear being always eastwards. The maximum amount of the eastward shear was 8 feet and occurred at the village of Kaigenkō ; while the maximum northward depression of 4 feet occurred at the last named place, and also at and near the crossing of the fault with the Sanjōkei river. Along the Chinsekiryō fault, the depression was also always on the north side, and the shear, whose maximum amount was 5 feet, was eastwards. In this case, the vertical dislocation was slight and less than 1 foot, being often indicated only by a gradual depression which caused the waters in the puddy fields to be collected on one side of the line of disturbance, leaving the other side dry.

To the west of Dabyō there was no surface manifestation of tectonic disturbances. But it seems probable that there exists an underground continuation of the fault for about 12^{km} in the direction of west slightly south, as far as the vicinity of the city of Shinkō. Along the zone about this imaginary fault, which is marked in Pl. XVIII by a dotted line, there was an ejection of large quantity of sand and water. Especially, in the vicinity of the villages of Tanshiken and Saikōseki, the ejected sand reached a thickness of

more than two feet and covered wide areas sometimes half a kilometre or more in width. (See Fig. 7.) The enormity of water ejection in these places may be judged from the fact that the police authorities, who tried to rescue people from under the ruined houses, were in some instances prevented from immediately approaching the latter, owing to the large quantity of mud water which flooded the surrounding grounds. The total length of the fault between Baishikō on the east and Tanshiken on the west is $25\frac{1}{2}^{km}$.

5. *Relation to the Faults of the Direction of (Vibratory) Motion.* Fig. 3 (Pl. XVIII.) indicates the general course of the faults, the directions of the (vibratory) motion at the different places, and the boundary of the area of the severest shock. This latter area is slightly different from that bounded by the line (1) in Fig. 1, and includes those towns and villages, in each of which more than 50 dwelling houses were completely destroyed or more than 15 persons were killed.

The directions of motion at the different places in this meizoseismal area determined from overthrown bodies, were as follows :—

Kagi	Toward	ESE.
Shinkō...	,,	ENE.
Suigiuseki	,,	SE.
Seiho	,,	E.
Dabyō	,,	E slightly S.
Baishiko	,,	SSE.

Thus it will be seen that the earthquake motion in the meizoseismal area was not perpendicular to the fault zone, but was, on the whole, directed from the western to the eastern end of the latter, in the same sense as the shear of the depressed side,

with the exception of the eastern extremity of the main fault. This seems to indicate that the tectonic disturbances were the result of the existence in this part of the earth's crust of a pressure or shearing forces in a driection nearly transverse to the longer axis of the island of Formosa, which finally produced the faults, such that the first shock or sudden movement of the ground was westwards, and the counter or greatest one eastwards. Probably both sides of the fault zone were displaced eastwards, the shear of the depressed side being the differential amount due to the greater eastward displacement of the latter.

The disturbances of the ground along the two faults above described were similar to those observed in other cases, the depression and the horizontal shear being generally combined. There were also the usual *secondary shear cracks,** whose inclination to the course of the dislocation zone was on the average about 43°. At some places along the main fault there were marked forcing up of the ground, due to the coexistence of compression. On the other hand, the wide crack which appeared near Chinsekiryō, was the result of a tension or a tendency to tear ashunder the two sides of the fault plane.

6. *Probable Eastward Extension of the Fault.* The boundary of the meizoseismal area given in Pl. XVIII. is evidently not complete and represents only the western half, the eastern half including mountainous regions inhabited by the savages, whence we could get no earthquake reports. Thus it is extremely likely that the main fault did not end at the vicinity of Baishikō, but was continued eastwards amoung the mountains for a further distance of 20 or 25^{km}. This supposition consistently explains why the

* See the *Bulletin*, No. 1, p. 13.

depression and shear phenomena at the eastern end of the Dabyo-Baishiko fault zone were opposite to those along the rest of the latter. The fact was probably as follows :—the fault had an extension of about 50^{km} and its most central point was between Bishō and Kaigenkō, the amount of the disturbances being greatest near these two places ; further, along the western half of the zone in question the ground on the north side was depressed and sheared eastwards, while along the eastern half the ground on the south side was depressed and sheared westwards. (See the next Article.)

The most central point of the epifocal zone as sssumed above may probably be taken to be between the villages of Bishō and Kaigenko, say, at

$$\begin{cases} \textit{Longitude}, & 120^\circ\ 32'\ \text{E.} \\ \textit{Latitude}, & 23^\circ\ 35'\ \text{N.} \end{cases}$$

7. *Duration of the Preliminary Tremor.* The approximate position of the centre of the earthquake may also be inferred from the duration (y) of the preliminary tremor recorded by Omori Horizontal Pendulums at the different meteorological observatories in Formosa. The epicentral distance (x) in the following table have been calculated by the formula*

$$x^{km} = 7.27\ y^{sec} + 38^{km}.$$

Earthquake of March, 17, 1906.

Place.	Duration of Prel. Tremor $= y$.	Epicentral Distance $= x$.
Taihoku	27.5 *sec.*	238 *km*
Taichu	9.0	104
Tainan	8.7	101
Hokoto	11.5	122

* The *Publications*, No 13.

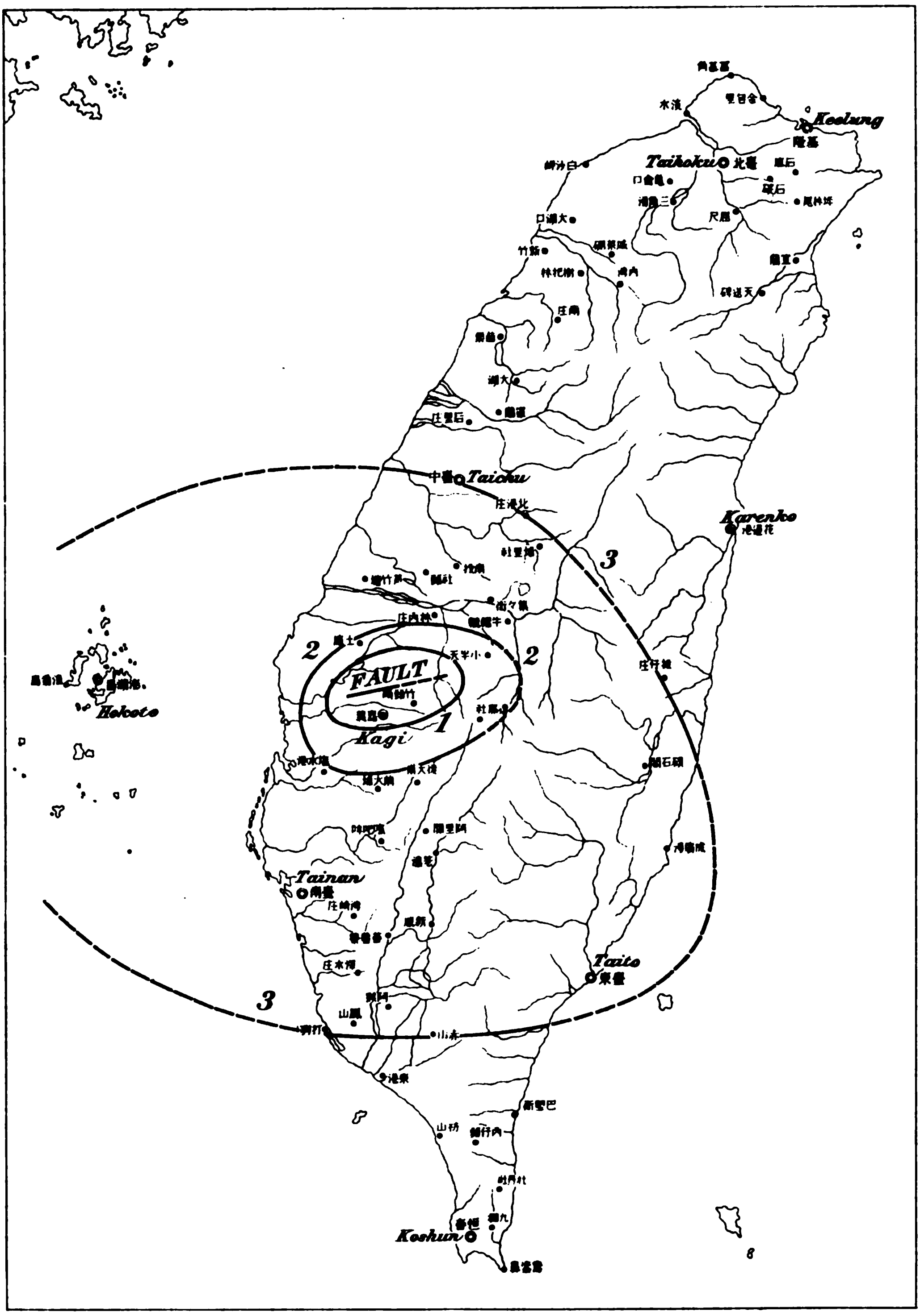
The circles drawn upon a map of Formosa about these four places with radii respectively equivalent to the calculated values of the epicentral distances enclose an area, whose centre roughly coincides with the region midway between the cities of Dabyō and Baishiko.

3. ***The Two Severe Earthquakes in* 1904.** The earthquake on the early morning of Nov. 6, 1904, at 4h 25m, caused a large amount of damage in the three prefectures of Toroku, Kagi, and Ensuiko, the casualties and the number of houses damaged being as follows.

Prefecture.	Casualties.		Number of Houses damaged.		
	Killed.	Wounded.	Totally destroyed.	Greatly damaged.	Slightly damaged.
Kagi	133	132	425	1021	1453
Toroku	10	16	62	60	517
Ensuiko... ...	2	0	3	4	5
Sum	145	148	490	1085	1975

Thus the number of the killed was nearly equal to that of the wounded, which is much different from what is usually the case in which the number of the wounded much exceeds that of the killed. According to the above table, 1 person was killed for every 3.4 houses totally destroyed. This ratio is much smaller than what takes place in Japan proper: thus, for instance, in the great Mino-Owari earthquake of 1891, there was 1 person killed for every 11 houses totally destroyed. These peculialities in the Formosa earthquake are evidently due to the bad construction of the native houses in the island, as remarked in § 2. As can easily be demonstrated, a very bad material of construction, which possesses no tensile strength, has a very serious defect, namely, it causes

Fig. 1. Map Showing the Isoseismal Lines of the Earthquake of March 17, 1906.



⊙………… Meteorological observatory.

•………… Station for Precipitation observation.

Fig. 2. Map. Showing the Actual Trace of the Baishikō and Chinsekiryō Faults.

(Towns, villages, rivers, and railroads only are shown.)

The red shade is the depressed side, the arrow indicating the direction of shear of the latter.
The figure in the shade gives the amount of depression, while that at the point of the arrow indicates the extent of shear.
The eastern continuation of the main Fault is lost among the mountains.

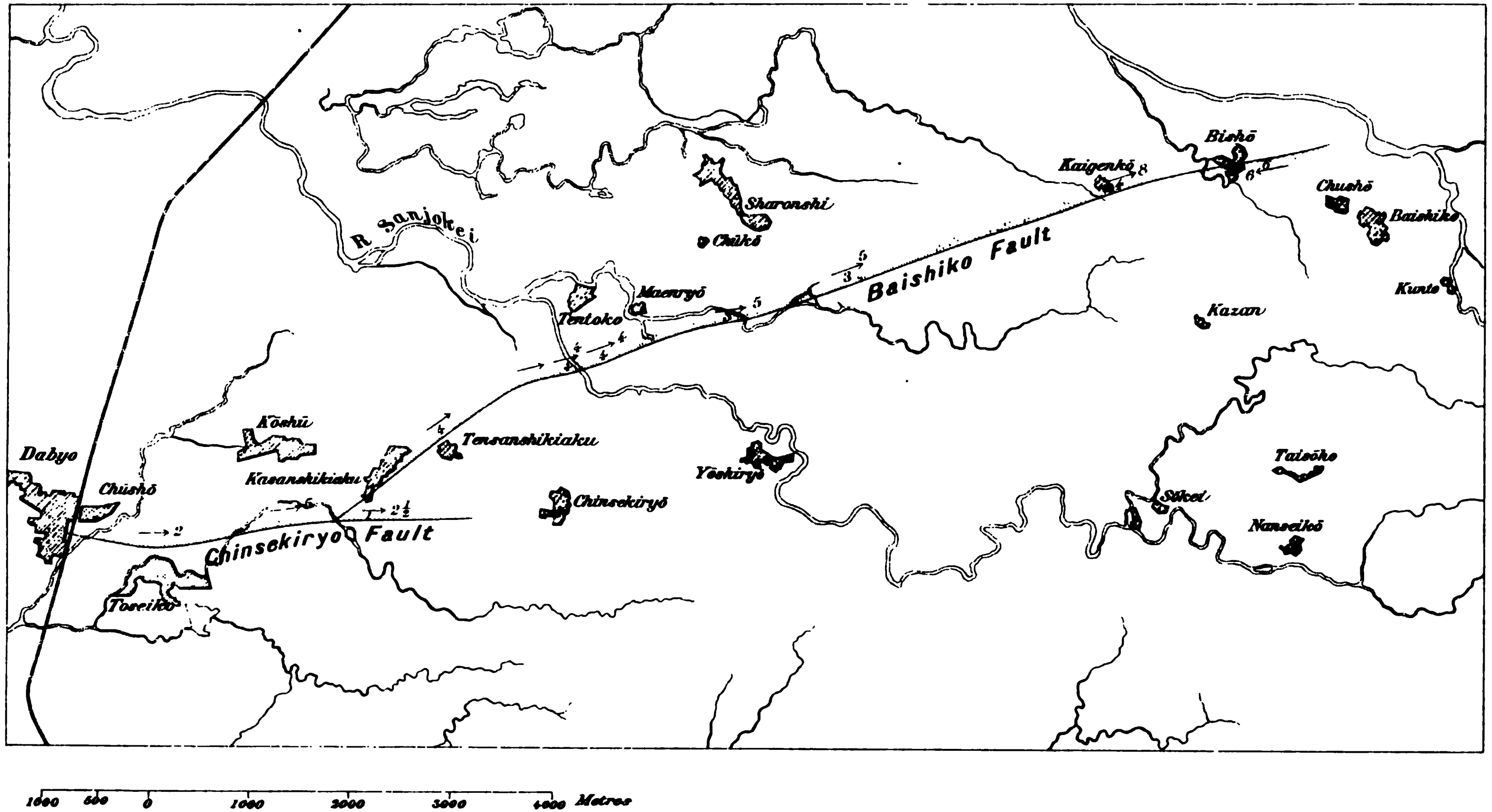
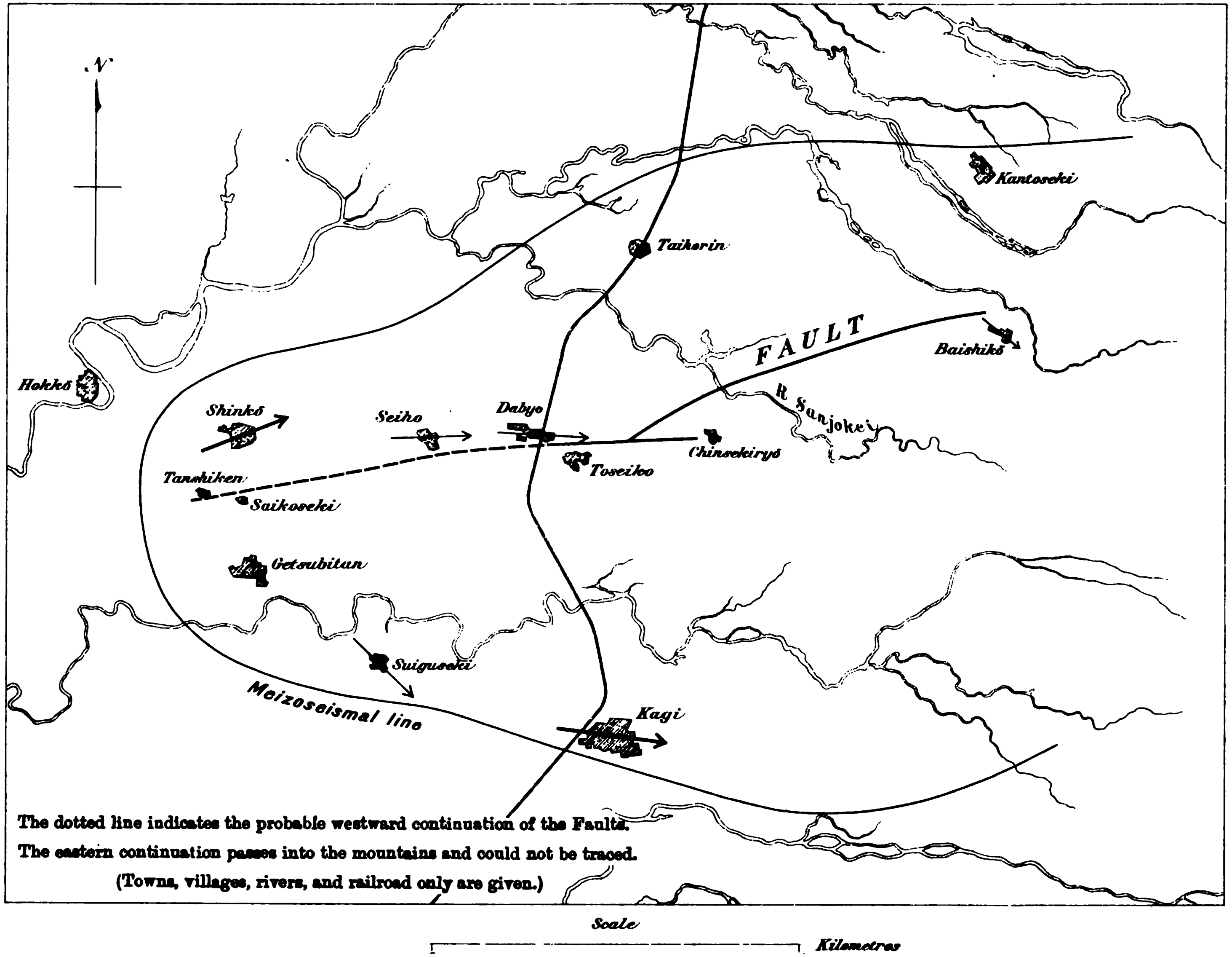


Fig. 3. Map Showing the Meizoseismal Line, the General Course of the Faults, and the Directions of Motion at the Different Places.



The dotted line indicates the probable westward continuation of the Faults.
The eastern continuation passes into the mountains and could not be traced.
(Towns, villages, rivers, and railroad only are given.)

The Baishikō Fault.

Fig. 4. Shear of the Taihorin-Baishikō Road; the foreground (southern side) sunk 6 feet and was displaced 6 feet westwards. (×) Mark the former continuation of the road.

Fig. 5. General view of the Fault from south-east. The left-hand (southern) side was depressed 6 feet, sloping down towards the fault line.

Fig. 6. Chinsekiryo Fault: a wide crack formed on a flat hill-top ground, the depth being more than 11 feet. A 2 ft. scale placed across the opening shows the width.

Fig. 7. Great Sand Eruption, near the village of Saikoseki. The cultivated fields were covered with sand to a depth of 2 feet.

Fig. 8. The New Sub-Prefectural Office Shinko, showing the effects of vibration of the front tower. The building was of wood, with plastered walls.

Fig. 9. The native Maso Temple, in the city of Shinko. The building was completely destroyed owing to bad masonry and weakness of wooden timbers on account of ravages of white ants.

the seismic stability of the wall to be nearly independent of the thickness; very thick walls of the Formosan *dokaku*, therefore, being thrown down by earthquake shocks quite as easily as thin ones. Had the same earthquake taken place in small towns of Japan proper the casualties would have been very slight. The intensity of motion in the most strongly shaken area was nearly half of that at Gifu or Ōgaki on the occasion of the Mino-Owari earthquake.

In Formosa there are also a large number of houses or cottages, built of bamboo, with very light roofs. These were of course not damaged by the earthquake. Wooden buildings in ordinary Japanese style also received no particular damage, except cracking of plastered walls and the disturbances of roof tiles.

The area of destructive motion was a narrow zone, whose length and breadth were about 57 and 23^{km} respectively. This zone, whose longer axis was in a NNE-SSW direction, stretched from the vicinity of the town of Toroku on the north to the vicinity of the village of Shin-eisho in the south ; the shock having been strongest in the district between the towns of Shinko and Kagi, at the middle of the area under consideration, or at about *lat.* 23°30′ N, and *long.* 120°26′ E.

The earthquake of April 24, 1904, at 2^h 39^m P.M. which also disturbed the south-western part of Formosa, was not so violent as that of Nov. 6, but its area of disturbance was much larger, and the zone of severe motion, whose length and breadth were 123 and 32^{km} respectively, ran in a NNE-SSW direction from the vicinity of the town of Toroku on the north to the vicinity of Banshoryo and Hozan on the south.

The position of the centre of each of the two earthquakes of April 24 and Nov. 6, 1904, may also be determined from the

duration of the preliminary tremor observed at the different places, the epicentral distance being calculated by the same formula as that given in § 7.

Earthquake of April 24, 1904.

Place.	Duration of Prel. Tremor $=y$.	Epicentral Distance $=x$.
Taihoku	28.7 *sec.*	246 *km.*
Taichu	11.4	120
Taito	12.8	131
Hokoto	12.7	130

Earthquake of Nov. 6, 1904.

Place.	Duration of Prel. Tremor $=y$.	Epicentral Distance $=x$.
Taihoku	28.8 *sec.*	246 *km.*
Taichu	11.2	119
Tainan	8.8	98
Taito	15.5	150
Hokoto	9.0	108

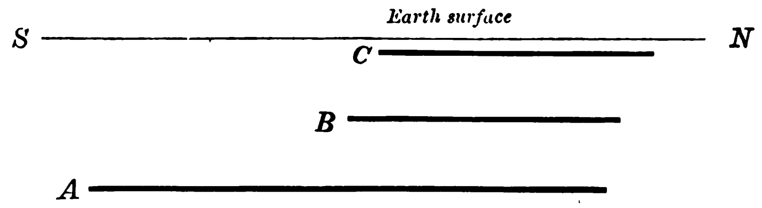
The circles drawn, for each of the two earthquakes, about the different places with the radii equivalent to the corresponding epicentral distances enclose an area, whose centre approximately coincides with the middle of the meizoseismal zone already mentioned.

9. *Relation of the Earthquake of March* 17, 1906, *with those in* 1904.* The violent earthquake of Nov. 6, 1904, was small in area, and its epifocus had a length of only 57^{km}, nearly coinciding with the northern half of that of the earthquake of

* The times are given in that of *long.* 120° E. of Greenwich.

April 24 in the same year, whose epifocal zone had a length of 123^{km}. Thus the April earthquake was, in magnitude, 2 or 3 times greater than the November one, while the intensity of motion in the latter was very much higher than in the former, the difference in the amount of the damage and casualties being also considerable.* It is evident, therefore, that the focus of the 1st earthquake was deep, while that of the 2nd was shallow. The two seismic foci may diagrammatically be represented by the two lines

Fig. 10.



A and *B* respectively (Fig. 10). It is probable that the second earthquake was in some way connected with the first; and, as the direction of the maximum displacement at the different places was in the 2nd earthquake generally directed *toward* the epifocus, which implies an initial outward motion, the cause of these two shocks was probably the sudden formation in an N-S direction of an underground cavity, the 2nd earthquake being due to an upward extension of the latter at its northern part. Thus it was to be inferred that the earthquake of Nov. 6, 1904, was only a disturbance which marked an intermediate stage in the development of the seismic activity along the zone under consideration, leaving a possibility of the occurrence of a final destructive shock, whose origin would be quite near the surface and at the northern end of the epifocal zone of the earthquake of April 24, 1904.

* These two earthquakes are Nos. 15 and 16 given in the Table, § 1.

From these considerations, and also because such severe but local shocks as those which happened in the south-western part of Formosa, often take place successively at neighbouring places in the course of a few years, I stated at the time of my visit to Formosa in the end of 1904 that the districts about Kagi might be visited after some years by a third shock, against which, however, it would be possible to make structures earthquake-proof, provided proper cares be taken in the building.* My anticipation was, in a measure, fulfilled by the occurrence of the earthquake of March 17, 1906, although its epifocal zone was at right angles to those of the two preceding ones.

After the occurrence of the destructive shock of March 17, accompanied by the formation of remarkable faults, it was to be expected that the next severe shock, if any, would rather have its origin displaced southwards and at a greater depth such that the surface intensity would not be so very violent. I have stated this view in a Tainan daily newspaper, the "Tainan Shinpō," of April 13, 1906, and on the next day, April 14, there took place an earthquake, nearly as extensive as that of March 17, the origin however, having been displaced about 10 miles towards the south, so that the city of Kagi was now at the northern limit of the area of destructive motion. The position of the origin of the earthquake of April 14, which was accompanied by no surface fault, was approximately

$$\begin{cases} \textit{Longitude}, & 120^\circ\ 30'\ \mathrm{E} \\ \textit{Latitude}, & 23^\circ\ 25'\ \mathrm{N}. \end{cases}$$

10. *Periodic Repetitions of Strong After-shocks.* The violent earthquak of March 17, 1906, was followed by numerous

* F. Omori: "on the Earthquakes in Formosa." *Reports* (Japanese) *of the Imperial Earthquake Investigation Committee*, No. 54.

after-shocks, attended by the usual phenomena of sound. What was very peculiar in this case was the abnormal severity of many of these subsequent shocks, some of which, like the severe earthquake of April 14, was in reality not an after-shock at all, but rather a separate manifestation at a different place of the same seismic activity which caused the first great shock. The following table gives a list of the more prominent among the after-shocks, which occasioned more or less damage.

No.	Date. 1906.	Time of occurrence at the origin.*	Prefecture.	Number of Killed.	Number of Wounded.	Number of Houses totally destroyed.	Number of Houses partially destroyed.
Initial Eq.	March 17	h m s 6. 42. 30 A.M.	Toroku.	11	35	254	293
			Kagi.	1237	2338	5345	2900
			Ensuikō.	1	5	63	40
1	March 26	11. 29. 20 A.M.	Toroku.	0	4	16	17
			Kagi.	1	1	4	26
2	April 4	8. 42. 00 P.M.	Kagi.	0	0	5	—
3	April 6	2. 58. 00 A.M.	Kagi.	0	4	39	59
4	,, 7	0. 52. 40 P.M.	Ensuikō.	1	2	13	35
5	,, 8	6. 39. 40 A.M.					
			Kagi.	9	56	829	1320
			Toroku.	1	4	34	55
			Ensuikō.	3	17	659	482
6	April 14	3. 18. 00 A.M.	Tainan.	0	3	6	25
7	,, ,,	7. 52 00 ,,	Banshoryō.	2	4	4	15
			Hōzan.	0	2	2	7
			Shōka.	0	1	5	1
			Taichu.	0	0	1	1

It may here be noted that the study of the after-shocks of the Mino-Owari and other recent large Japan earthquakes has shown the existence of a series of periods in the variation of the number and intensity of these shocks, the most well-defined ones being $4\frac{1}{2}$ days, 8 or 9 days, about 12 days, and about 33 days, in length.

* Times are given in that of longitude 120° E.

Of these, the first is evidently the fundamental period, and the others are probably its multiples.* I have recently examined the variation from day to day of the atmospheric pressure for Tokyo, Gifu, and for whole Japan, and found the periods of 4.6 days, 9.0 days, and 34 days. It thus seems highly probable that the different periods in the seismic frequency above mentioned are due to the fluctuations in the barometric pressure.†

Now what is very interesting of the after-shocks of the Formosa earthquake of March 17, 1906, is the regularity with which strong shocks happened successively, the period being that of 9 days. Thus the first strong after-shock (No. 1 in the foregoing table) took place on March 26, about 9 days 5 hours after the initial violent earthquake. As this circumstance seemed to indicate the predominance of the 9-days periodicity, I predicted the possible repetitions of strong after-shocks at this interval. This was practically verified, and the next severe shock (No. 2) occurred on April 4, about 9 days 9 hours after the first (No. 1), the strong shocks Nos. 3, 4, and 5 being regarded as forming a group with No. 2. Thus the inhabitants in the city of Kagi and other places began to put great faith in the periodicity of the recurrence of seismic phenomena, such that on the night of April 13, which happened to be 9 days after April 4, the date of the shock No. 2, many people anticipated the occurrence of a strong disturbance and did not go to sleep. As a matter of fact there took place the next morning two very severe earthquakes, the time interval in this case being 9 days 7 hours.

* F. Omori: "The After-shocks of Earthquakes." Jour. Coll. Sc., Imp. Univ. Tokyo, Vol. VII, Part 2.

† F. Omori: "On long-periods Variations of the Atmospheric Pressure" *Reports* (Japanese). *of the Imp. Earthquake Investigation Committee, No. 57.*

The earthquake No. 7, which was the strongest among the after-shocks, apparently restored the equilibrium of the disturbed earth's crust in this part of Formosa, there being no subsequent severe shock.

Tokyo.

January 1907.

Comparison of the Faults in the Three Earthquakes of Mino-Owari, Formosa, and San Francisco.

By

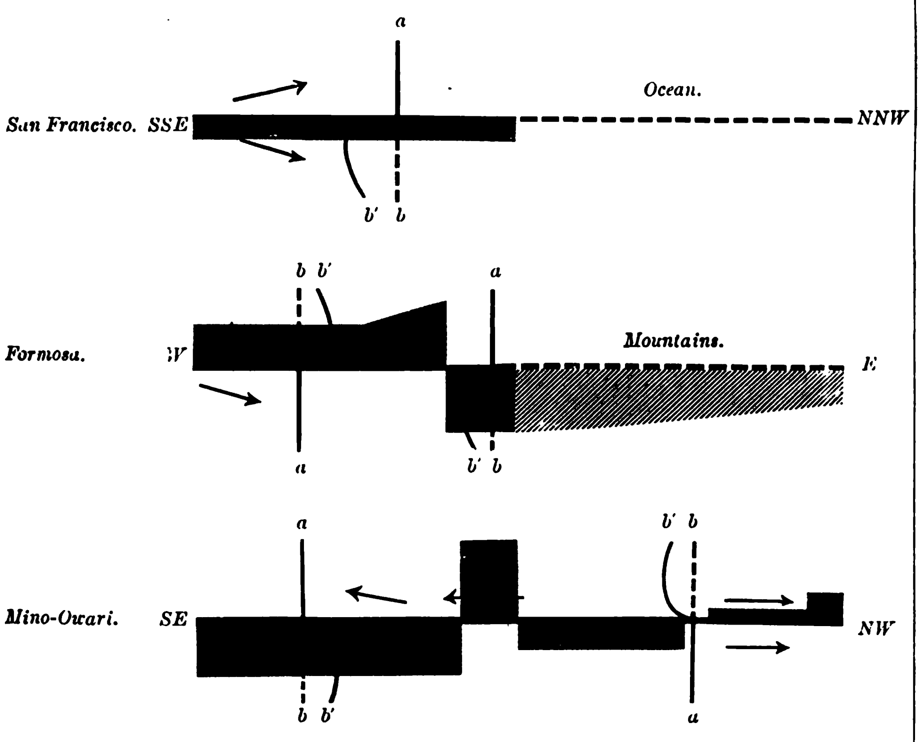
F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

The three great earthquakes of Mino-Owari (Central Japan) on Oct. 28, 1891, of Kagi (Formosa) on March 17, 1906, and of San Francisco on April 18, 1906, were each accompanied by the formation of remarkable *faults*, whose total lengths were about 100, 50, and 430^{km} respectively. The dislocation in the San Francisco earthquake was formed partly along, and partly off, the west coast of California, belonging to the category of longitudinal faults. The dislocations in the Mino-Owari and Kagi earthquakes were, on the other hand, formed nearly at right angles to the course of the Main Island (Nippon) and the axis of Formosa Island respectively, both belonging to the category of transverse faults. Notwithstanding these differences, there are certain similarity among the three cases. Thus, in each earthquake, the direction of motion at different places in the immediate neighbourhood of the fault was not perpendicular, but more nearly parallel, to the latter. This seems to indicate that the formation of the faults was mainly due, in each case, not to such actions as the simple falling down or sudden creation of a cavity underground, but to the existence of shearing stresses in the plane of fracture, possibly of two opposing forces acting either from the centre toward both ends of the fault line, or toward the centre from both ends.

The accompanying figure is a diagrammatic illustration of the 3 faults, the line *ab* indicating, in each case, a straight line (say, road) which suffered a shearing movement in such a way that the part *b* on the depressed side was displaced to the new position *b'*, being generally transformed into a curve.

From the figure it will be seen that there existed in each fault what may be called the central point, where the disturbance of the ground is greatest and about which the shear and depression along the line of dislocation is more or less symmetrical.



Full line ....Fault (ascertained).
Dotted line....................*Probable* continuation of fault.
Shaded part .. ..Depressed region.
Lightly shaded part..... ...Probable depression.
Arrow ....Direction of maximum (*vibratory*) motion.

In the case of the Mino-Owari earthquake the central point was in the vicinity of the village of Midori in the Neo-Valley, where a very remarkable depression of the ground took place. The corresponding point on the Formosa fault was between the villages of Bisho and Kaigenkō. In the San Francisco earthquake the northern half of the fault was under the ocean, but the central point was probably in the vicinity of the Tomales Bay, the greatest amount of disturbance having occurred there.

The greatest vertical dislocation of 18 feet occurred in the Mino-Owari earthquake, while the greatest horizontal shear occurred in the San Francisco earthquake. The latter has shown a vertical displacement of only 1 or 2 feet, while the former was accompanied by a large horizontal shear of about 18 feet. In the Formosa earthquake, whose magnitude was much smaller than the other two, the vertical and the horizontal displacements of the ground were each of a moderate scale, the maximum amounts being 6 and 8 feet respectively.

The maximum vibratory motion in the Mino-Owari earthquake showed a tendency of being directed from the central point towards both ends; while, in each of the two other earthquakes, the same motion was, as far as can be ascertained, directed from one end towards the centre. Again, the direction of the maximum (vibratory) motion was, in the Formosa earthquake, the same as that of the shear of the depressed ground. In the two other earthquakes, however, the reverse was the case. These differences are probably due to the diversity in the manner of the action of the force along the fault plane which finally produced the dislocations.

Note on the Transit Velocity of the Formosa Earthquakes of April 14, 1906.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

1. The time of occurrence of the severe Formosa earthquake in the morning of April 14, 1906,* has been exactly observed by the present writer with a chronometer watch, at Taichu whose epicentral distance is about 90^{km}. The earthquake was also satisfactorily registered by the Omori Horizontal Pendulums at Tokyo, whose epicentral distance is 1710^{km} or 15.°4. The times‡ of occurrence at these two places were as follows :—

Tokyo	$8^h\ 56^m\ 46^s$ A.M.
Taichu...	8 52 22 ,,
Difference	$4^m\ 24^s$

As the difference of the epicentral distances of the two places is 1620^{km}, we obtain a mean transit velocity of 6.15^{km} per sec.

2. The above earthquake was preceded by another shock of nearly an equal extension, whose time of occurrence observed at the Meteorological Observatory of Taichu was, with proper time corrections, $4^h\ 18^m\ 20^s$ A.M. The time of the same earthquake registered by the seismographs at Tokyo was $4^h\ 22^m\ 20^s$ A.M.‡ From these observations we obtain :—

Time difference between Tokyo and Taichu $=4^m\ 0^s$.
Mean velocity ,, ,, ,, ,, $=6.75^{km}$ per sec.

* See page 66.
‡ These times are given in that of longitude 135° E.

3. Supposing the value of the transit velocity given in § 1 to be twice as accurate as that given in § 2, and taking the mean, we obtain :—

$$\text{velocity} = 6.35^{km} \text{ per sec.}$$

This value which relates to the distance difference between the epicentral arcual length of 0.°8 and 15.°4, although it is the result of calculation by the *difference method*, is really that calculated by the *direct method*, as one of the places taken for comparison, namely, Taichu, was quite near the earthquake origin.

Notes on the Valparaiso and Aleutian Earthquakes of Aug. 17, 1906.

By

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Member of the Imperial Earthquake Investigation Committee.

1. ***Introduction.*** It is a quite remarkable fact that, on Aug. 17, 1906, almost simultaneously with the great Valparaiso earthquake there was another large shock off the Aleutian Islands. As will be seen from later §§, the Valparaiso shock occurred at 0^h 40^m 05^s (G.M.T.), the approximate position of the origin being $\varphi=31°$ S, $\lambda=73°$ W. The other earthquake took place 28^m 21^s earlier, or at 0^h 11^m 44^s (G.M.T.), the origin being approximately at $\varphi=50°$ N, $\lambda=175°$ E. As will be seen from Fig. 1, the latter position is on the outer side of the Aleutian Islands arc, where the sea bottom quickly descends to the north Pacific basin whose depth is over 7000 metres. The topography of the vicinity of the origin of the Valparaiso earthquake is also highly characteristic, there being a marked contrast between the depth of the water and the elevation of the mountains. Thus, there is, quite close to the coast, the Chile basin, where the water depth is over 7600 metres, (Fig. 2), while the peak of Aconcagua, in the Andes, reaches an elevation of 6970 metres.

The Aleutian earthquake furnishes an instance of the seismic manifestation along the exterior, or convex, side of an arc formed by a series of islands or mountain chains, such side being generally much steeper than the inner, or concave, side. The Japanese Islands, the Himalayan mountains and the two islands of Java and

Sumatra are other good examples of the relation of the seismic activity to the curvilinear topographical form.*

2. ***Relation between the Valparaiso and Aleutian Earthquakes.*** The centres of the two earthquakes of Valparaiso and Aleutian Islands are separated by an arcual distance of 126° 56′, or by a little more than two-thirds of the earth's semi-circumference. The interesting feature is that these two disturbances were no independent phenomena, but were simultaneous manifestations of seismic energy at both ends of the great earthquake zone extending along the whole Pacific coast of North and South America. The latter zone is indicated, in Fig. 3,‡ by a line marked 5......6, the numerals 1, 2, 3 and 4, indicating the approximate positions of the different previous earthquakes, as follows :—

(1)............Alaska Earthquakes of 1899 and 1900.

(2)............Mexico and Central America earthquakes of 1900 and 1902.

(3)............Panama, Columbia and Equador earthquake of 1906.

(4)............San Francisco earthquake of 1906.

5 and 6 indicate respectively the origins of the Aleutian and Valparaiso earthquakes. The position of the centre of the first of the last mentioned disturbances is near to the Kuriles and Hokkaido and may be regarded as the approach to the north-eastern part of Japan of the great seismic activity already manifested along the other side of the Pacific. The successive occurrence of large destructive earthquakes along the zone extending from the north

* These relations have been discussed in detail by the present Author in the *Reports* (Japanese) *of the Imp. Earthquake Inv. Com., No.* 49. See also the next Article.

Figs. 1 and 2 are based on "Stiller Ozean" edited by Seewarte (Hamburg).

‡ This is a slight modification of Fig. 20, given on page 22, of the *Bulletin*, No. 1.

Mediterranean to the Himalayas, and possibly to Formosa, has already been noted in the *Bulletin*, No. 1.*

3. *Seismograms.* As stated before, the Aleutian earthquake occurred nearly half an hour before the Valparaiso earthquake. The motion due to the latter disturbance was, therefore, in the seismographic records partly confused by that due to the former. In the seismograms obtained at the different Japanese stations, however, this circumstance caused no mistake, as the commencement of the Valparaiso earthquake was clearly indicated by the appearance of small quick vibrations usually marking the 1st preliminary tremor of the seismic motion. The Vicentini seismogram obtained at Manila also shows clearly the vibrations due to the Chilian earthquake.

I have here to express my thanks to the Directors of the Observatories of Osaka, Manila, Ximeniano, Querce, and other places, who have kindly supplied me with the copies of the seismograms relating to the two earthquakes in question.

Most of the observers in Europe have, in the analysis of the seismograms, mistaken the first or Aleutian Earthquake for that of Valparaiso, the only exceptions as far as I know being Padre Alfani and Professor Wiechert. Padre Alfani has written a note on the results obtained at the Ximeniano observatory, giving $0^h\ 58^m\ 15^s$ (G.M.T.) for the commencement of the 2nd (Valparaiso) earthquake.‡ Professor Wiechert gives $1^h\ 13^m\ 30^s$ (G.M.T.) for the corresponding phase of motion observed at Göttingen.

I give next the result of the analysis of the seismograms obtained at Tokyo, Osaka, Manila, and Querce. As usual, the

* See also next Article.

‡ Padre Alfani: "Appunti sul Terremoto di Valparaiso." *Rivista di Fisica, Matematica e Scienze Naturali* (Pavia), No. 82. 1906.

symbols a, $2a$, and T, will be used to denote respectively the amplitude, double amplitude, and the complete period of vibration. *The times are always given in G.M.T.*

ANALYSIS OF THE SEISMOGRAMS.

4. *Observation at Hongo, Tokyo.*

(i) **EW Component.** Fig. 5, Pl. XXIV.

Pl. XXIV is a reproduction of the EW Component diagram given by a horizontal pendulum set up in the brick "earthquake-proof house," at Hongo, the instrumental constants being as follows*

Period (complete) of free oscillation=28 sec.

Multiplication of the pointer=10 times.

Weight of the heavy cylinder=14 kg.

Length of the horizontal strut, or the distance between the centre of the heavy cylinder and the point of support=1 metre.

Vertical distance between the points of support and of suspension=2.5 metres.

Aleutian Earthquake. Commencement=$0^h\ 17^m\ 20^s$.

Preliminary Tremor. Duration=$5^m\ 23^s$. During the first $1^m\ 5^s$, the motion was very small, the commencement being slightly uncertain :— T=6.4 sec.

For the next $1^m\ 55^s$, the motion was well defined, forming the most active part in this phase :—

$$T=8.5 \text{ sec.,} \qquad 2a=0.35 \text{ mm.}$$

* This is one of the horizontal pendulums constructed in 1897, which has been referred to as A-apparatus in the *Publications*, No. 5.

The subsequent motion was smaller, consisting of the three following sets of vibrations :—

$$\begin{cases} T=\ 9.0 \text{ sec.,} & 2a=0.27 \text{ mm.} \\ T=\ 4.3\ \ ,, & \text{(small).} \\ T=30.9\ \ ,, & 2a=0.35. \end{cases}$$

Principal Portion. Commencement=0^h2[illegible]$^m\ 43^s$. [1st & 2nd phases.] Duration=$2^m\ 05^s$. The very first displacement was $a=$ 1.4 mm., directed towards W. The motion was as follows :—

During the 1st 50 sec .... $T=25.0$ s., $2a=2.9$ mm.

,, next $1^m\ 15^s$...... $\begin{cases} T=37.5 \text{ s.,} & 2a=2.0 \text{ mm.} \\ T=\ 8.0 \text{ s.,} & \text{———} \end{cases}$

[3rd phase]. Duration=$2^m\ 56^s$. The record consists entirely of nearly equal pendulum oscillations as follows :—

$T=27.1$ sec., max. $2a=9.8$ mm. (2nd vibration).

The very first displacement in this phase was $a=4.5$ mm., directed towards W.

[4th phase]. Duration=$3^m\ 2^s$:—

$T=20.2$ sec., $2a=5.6$ mm.

The subsequent motion was as follows :—

(i) During the 1st $10^m\ 00^s$:—

$$\begin{cases} T=19.4 \text{ sec.,} & 2a=1.78 \text{ mm.} \\ T=11.1\ \ ,, & ,,\ =1.20\ \ ,, \end{cases}$$

(ii) During the next $10^m\ 55^s$:—

$$\begin{cases} T=17.0 \text{ sec.,} & 2a=1.20 \text{ mm.} \\ T=10.5\ \ ,, & ,,\ =1.00\ \ ,, \\ T=34.5\ \ ,, & \text{———} \end{cases}$$

(iii) During the next $9^m\ 16^s$:—

$$\begin{cases} T=10.5 \text{ sec.,} & 2a=0.55 \text{ mm.} \\ T=18.7 \;\;,, & ,, =0.55 \;\;,, \\ T=\;\;8.3 \;\;,, & \text{(small).} \end{cases}$$

Then there appeared the commencement of the 2nd or Valparaiso earthquake.

Valparaiso Earthquake Commencement $=1^h\ 00^m\ 55^s$.

1*st Preliminary Tremor*. Duration$=18^m\ 58^s$. The commencement of the Valparaiso earthquake was marked by the appearance of small quick movements of T=about 4 sec., mixed with the vibrations constituting the end portion of the Aleutian earthquake. $7^m\ 45^s$ later on there appeared again some small movements, of similar sort which were probably the seismic motion propagated along the major arc between Chile and Tokyo. The elements of motion in this phase, which partly relates to the vibrations belonging to the Aleutian earthquake, were as follows :—

$$\begin{cases} T=\;\;9.3 \text{ sec.,} & 2a=0.53 \text{ mm.} \\ T=14.5 \;\;,, & ,, =0.5 \;\;,, \\ T=29.7 \;\;,, & \text{———} \end{cases}$$

The end of the 1st preliminary tremor was not well defined.

2*nd Preliminary Tremor*. Commencement$=1^h\ 19^m\ 53^s$. Duration $=23^m\ 36^s$. During the first $6^m\ 3^s$, the motion was comparatively small. During the next $3^m\ 15^s$, there were 6 regular vibrations :—

$$T=32.5 \text{ sec.,} \qquad 2a=0.85 \text{ mm};$$

mixed with small movements of T=9.3 sec.

The subsequent motion was as follows :—

(i) During $2^m\ 48^s$, the motion was small :—

$$\begin{cases} T=\;\;9.7 \text{ sec.,} & 2a=0.32 \text{ mm.} \\ T=18.9 \;\;,, & ,, =0.3 \;\;,, \end{cases}$$

(ii) During 59^s, there were 2 slow vibrations :—

$T=29.5$ sec., $2a=0.6$ mm.

(iii) During $5^m\ 47^s$, motion was small :—

$$\begin{cases} T=11.8 \text{ sec.}, & 2a=0.3 \text{ mm.} \\ T=\ 8.7\ \text{,,} & \text{,,}\ =0.2\ \text{,,} \end{cases}$$

Then, at $1^h\ 38^m\ 31^s$, the motion became again somewhat more active, possibly corresponding to the propagation along the major arc. The motion during the remaining $4^m\ 43^s$ was as follows :—

$$\begin{cases} T=11.2 \text{ sec.}, & 2a=0.42 \text{ mm.} \\ T=\ 8.2\ \text{,,} & \text{———} \end{cases}$$

The end of the 2nd preliminary tremor was not well defined.

Principal Portion. Commencement$=1^h\ 43^m\ 13^s$.

(i) During the 1st $8^m\ 32^s$:—

$$\begin{cases} T=\ 9.2 \text{ sec.}, & 2a=0.25 \text{ mm.} \\ T=12.5\ \text{,,} & 2a=0.25\ \text{,,} \\ T=37.7\ \text{,,}\ (?) & \end{cases}$$

(ii) During the next $2^m\ 44^s$:—

$T=32.8$ sec., $2a=0.6$ mm.

This part which probably corresponds to the 3rd phase of the principal portion, occurred at $1^h\ 51^m\ 45^s$.

(iii) During the next $8^m\ 33^s$, there were 2 max. groups :—

$$\begin{cases} \text{1st group.........Duration}=3^m\ 46^s; & T=22.6 \text{ sec.}, & 2a=2.35 \text{ mm.} \\ \text{2nd ,, ...Duration}=3^m\ 5?^s; & T=21.6\ \text{,,}, & 2a=2.0\ \text{,,}. \end{cases}$$

In the minimum part between these two maxima, there were small vibrations of $T=19.3$ sec.

(iv) During the next $11^m\ 40^s$:—

$T=18.3$ sec., $2a=0.74$ mm.

At minimum epochs there were small vibrations of $T=8.8$ sec.

(v) During the next 22^m 15^s :—

$T=19.0$ sec., $2a=0.5$ mm.

Then at 2^h 36^m 59^s, there took place two well defined vibrations :—

$T=20.0$ sec., $2a=0.75$ mm.

These may correspond to the 3rd phase of the principal portion propagated along the major arc. For the next 4^m 14^s :—

$T=22.1$ sec.

Thereafter the motion consisted of quick vibrations and gradually died away, with alternations of maximum and minimum groups. The motion during the subsequent successive epochs was as follows.

(i) During 6^m 34^s :—

$T=16.4$ sec., $2a=0.26$ mm.

(ii) During 6^m 57^s :—

$T=18.2$ sec., $2a=0.29$ mm.

(iii) During 5^m 10^s :—

$T=17.2$ sec., $2a=0$ 1 mm.

(iv) During 9^m 14^s :—

$T=15.8$ sec., $2a$ (small).

At 3^h 52^m 21^s there appeared again some slight slow vibrations of $T=18.3$ sec., which were probably due to the Aleutian earthquake, being the W_3 motion, or the repetition of the motion (3rd phase of the principal portion) first propagated along the minor arc.

(ii) Vertical Component. Fig. 6, Pl. XXIV.

Fig. 6, Pl. XXIV is a reproduction of the diagram given by a vertical motion seismograph, whose instrumental constants have been given in the *Bulletin*, No. 1, being as follows :—

Length of the vertical spiral springs = 1.2 metre.

Horizontal distance between the centre of the steady mass and the pivot = 1.2 metre.

Weight of the heavy bob = 9 kg.

Natural oscillation period = 6.0 sec.

Multiplication of the pointer = 12.

Aleutian Earthquake. Commencement = $0^h\ 17^m\ 11^s$.

Preliminary Tremor. Duration = $5^m\ 33^s$. The motion began with quick movements, the vibrations during the successive epochs being as follows.

(i) $1^m\ 5^s$.........T=3.3 sec., $2a$=0.05 mm.

(ii) $2^m\ 20^s$ ......Motion was active :—

$$\begin{cases} T=9.4 \text{ sec.}, & 2a=0.09 \text{ mm.} \\ T=5.2 \text{ ,,} & \text{,,} =0.15 \text{ ,,} \\ T=3.6 \text{ ,,} & \text{(small).} \end{cases}$$

(iii) $2^m\ 8^s$.........Motion was small and nearly uniform :—

T=3.5 sec., $2a$=0.03 mm.

Principal Portion. Commencement = $0^h\ 22^m\ 44^s$.

For the first $2^m\ 40^s$, the motion was small, but there were traces of some slow vibrations :—

$$\begin{cases} T=22.8 \text{ sec.}, & \text{———} \\ T=\ 4.7 \text{ ,,} & 2a=0.09 \text{ mm.} \end{cases}$$

Then set in the slow vibration epoch, the motion being most marked for the next $6^m\ 30^s$, as follows :—

(i) $1^m\ 8^s$.........There were 2 slow movements :—

$$\begin{cases} T=34.0 \text{ sec.,} & 2a=0.19 \text{ mm.} \\ T=\ 4.0\ \text{,,} & \text{(small).} \end{cases}$$

(ii) $1^m\ 11^s$.........There were 3 well defined vibrations :—

$T=23.7$ sec., $2a=0.22$ mm.

(iii) $4^m\ 8^s$.........The amplitude gradually decreased :—

$$\begin{cases} T=20.7 \text{ sec.,} & 2a=0.17 \text{ mm.} \\ T=12.4\ \text{,,} & \text{———} \end{cases}$$

The subsequent motion was small and regular, the vibrations during the successive epochs being as follows :—

(i)	5^m	5^s	............$T=21.8$ sec.,	$T=10.9$ sec.
(ii)	2	9	............$T=16.1$,,	
(iii)	1	50	............$T=11.0$,,	
(iv)	3	39	............$T=16.9$,,	
(v)	9	54	............$T=11.7$,,	

Valparaiso Earthquake. Commencement$=1^h\ 00^m\ 34^s$.

1*st Preliminary Tremor.* Duration = about 18^m. The commencement of the Valparaiso earthquake was indicated by the appearance of small quick vibrations :—

$T=3.5$ sec., $2a=0.12$ mm.

These vibrations existed more or less throughout this phase of motion. There were, however, some increase in amplitude at 6^m 35^s after the commencement of the earthquake, due probably to the propagation along the major arc.

2*nd Preliminary Tremor.* The motion now consisted entirely of slow vibrations, as follows :—

(i) During the first $7^m\ 16^s$: $T=11.1$ sec.

(ii) ,, ,, next $7^m\ 28^s$: $T=11.2$ sec.

3rd Phase of the Principal Portion. Commencement$=1^h\ 52^m\ 18^s$. The motion began with slow vibrations of $T=26.8$ sec., which were comparatively small during the first $3^m\ 7^s$. During the next $9^m\ 25^s$, the motion was most active :—

{(i) For the 1st $3^m\ 44^s$:—$T=22.4$ sec., $2a=0.046$ mm.
{(ii) „ „ next $5^m\ 41^s$:—$T=19.2$ „ $2a=0.05$ mm.

The subsequent motion was smaller, the T being$=17.1$ sec.

(iii) **EW Component.** Fig. 7, Pl. XXV.

Fig. 7, Pl. XXV gives the earlier part of the EW component of the Aleutian earthquake as recorded by a duplex horizontal pendulum apparatus* in the Seismological Institute, whose instrumental constants are as follows :—

Period of free oscillation$=41.5$ sec.

Multiplication of the pointer$=30$ times.

Weight of the heavy cylinder$=16.5$ kgm.

Length of the horizontal strut$=0.75$ metre.

Vertical distance between the points of support and of suspension $=1$ metre.

Aleutian Earthquake.

Preliminary Tremor. Duration$=5^m\ 5^s$. The very 1st displacement was well marked, being $a=0.04$ mm., directed toward W. For the next $1^m\ 3^s$, the motion was small :—

$T=5.0$ sec., $2a=0.05$ mm.

Then the motion became suddenly large, commencing with a displacement of $a=0.25$ mm., toward W, followed by the counter motion of $2a=0.43$ mm. toward E. During the next $4^m\ 2^s$, T was 8.3 sec.

* This is a portable form instrument described in the *Publications*, No. 18.

Pricipal Portion. The motion became much larger, the 4 initial displacements being as follows : —

(i)	a=0.25 mm.,	toward	W.
(ii)	$2a$=0.78 „	„	E.
(iii)	$2a$=1.72 „	„	W.
(iv)	$2a$=2.57 „	„	E.

Then the pointer went out of the smoked paper, toward W. The period of these vibrations was 31.2 sec., there being also some small movements of T=9.3 sec.

Later on the pointer again entered on the smoked paper, recording the end portion due to the Chilian earthquake : —

T=16.4 sec.

(iv) NS Component. Fig. 8, Pl. XXV.

The record was taken by a long period horizontal pendulum set up in the "earthquake-proof house," whose instrumental constants are as follows : —

Vertical distance between the points of suspension and of support =2 metres.

Effective length of the strut, or the horizontal distance between the point of support and the steady axis=1 metre.

Weight of the heavy bob=46 kgm.

Natural oscillation period=48.5.

Multiplication of the pointer=20.

Aleutian Earthquake.

Preliminary Tremor. Duration=5^m 19^s. The commencement is well defined, the initial displacement being a=0.06 mm., toward S. For the first 1^m 1^s, the motion was small : —

T= 5.1 sec., $2a$=0.06 mm.

Fig. 1. Aleutian Islands and the Surrounding Seas.

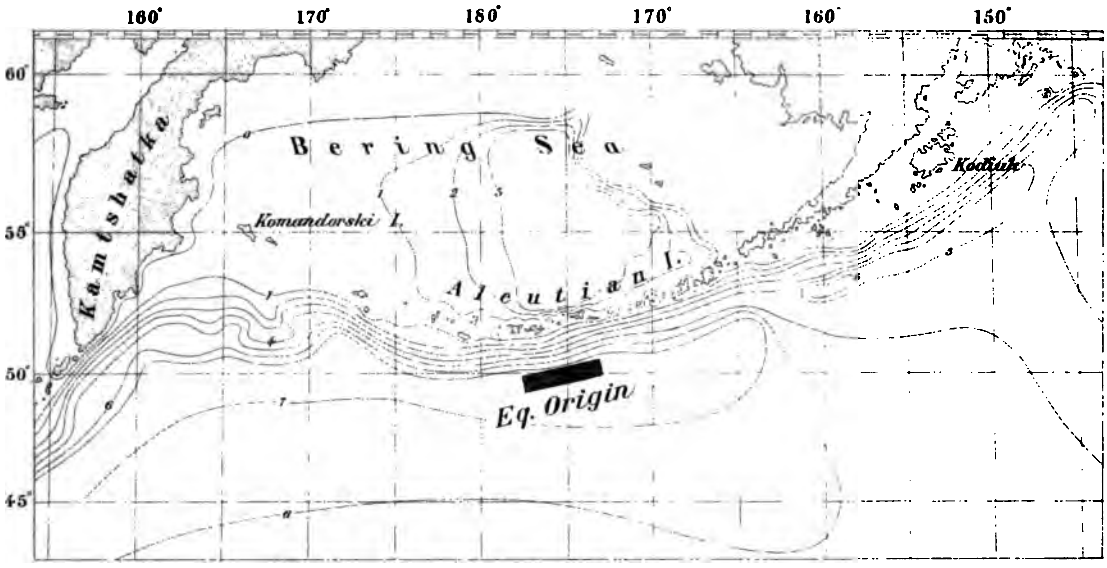


Fig. 2. Showing the Depth of Water off the West Coast of S. America.

In Figs. 1 and 2, the earthquake origins are in each case indicated by a short thick line.

Lines marked 0, 1, 2, ... 7 are the lines of equal depth of 200, 1000, 2000, and 7000 metres respectively

Erratum. Fig. 1, Pl. XXII. The earthquake origin has, by mistake, been placed at longitude 175°W. It ought to be put at longitude 175°E, the latitude being 50°N.

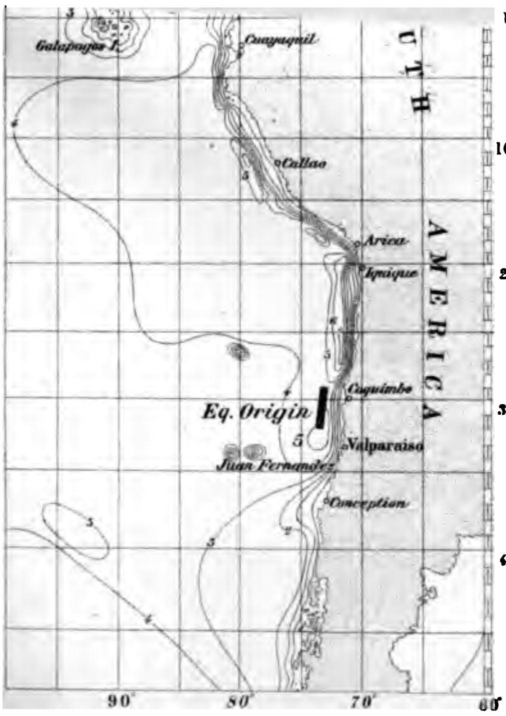
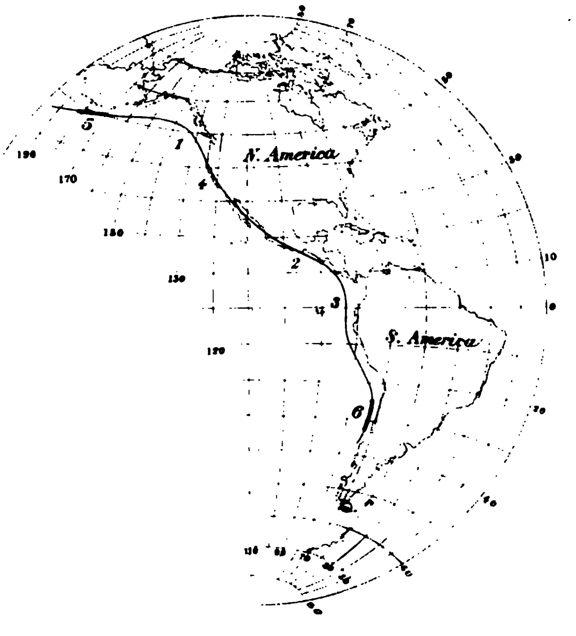
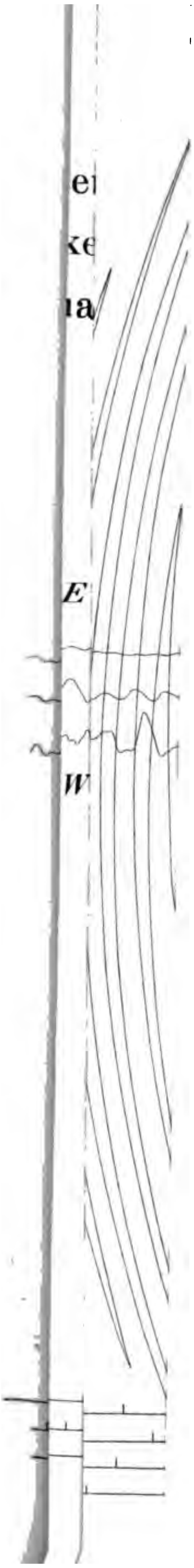
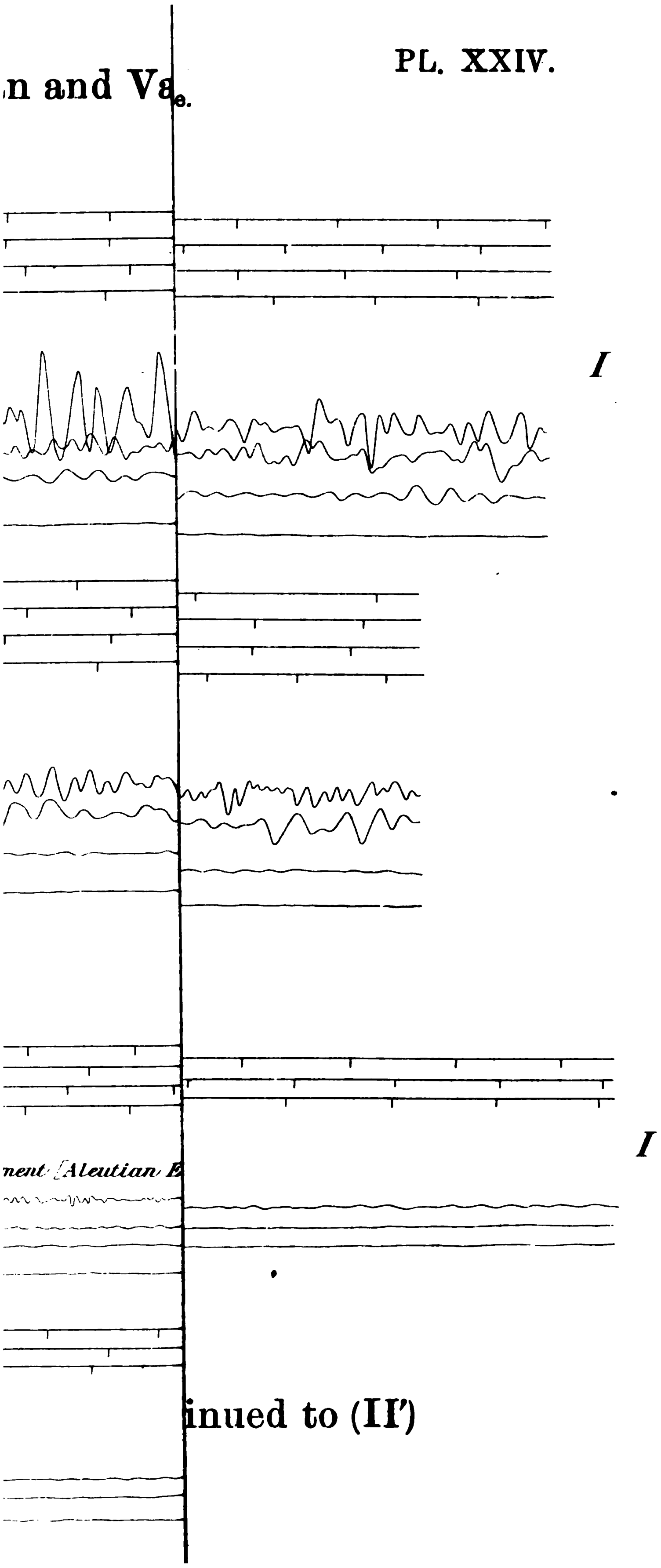


Fig. 3. Map showing the Approximate Positions of the different Great Earthquakes which took place along the West Coast of America.




E
W


n and Va e.
I
I
nent [Aleutian E
inued to (II')

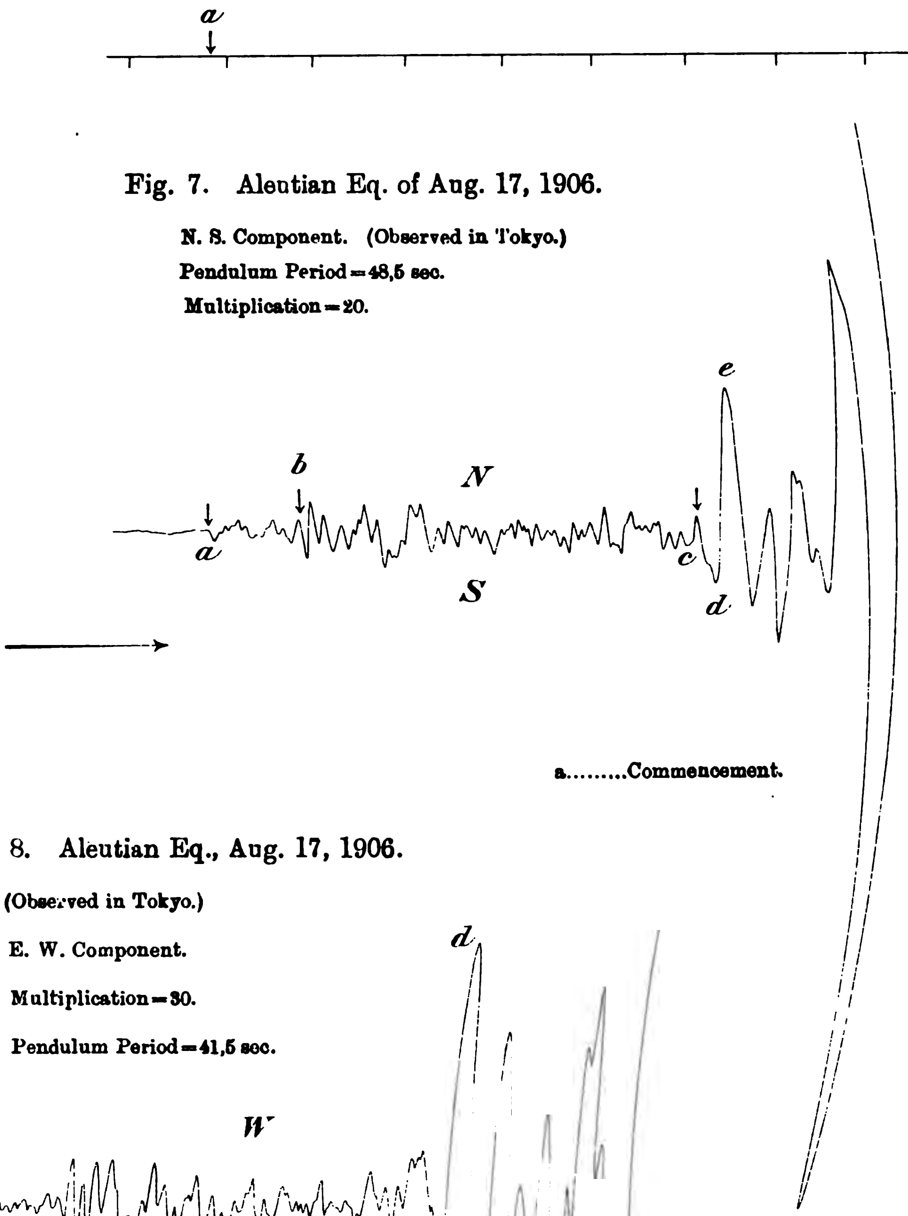
Time : 1 interval = 1 min.

Fig. 7. Aleutian Eq. of Aug. 17, 1906.

N. S. Component. (Observed in Tokyo.)

Pendulum Period = 48,5 sec.

Multiplication = 20.



a.........Commencement.

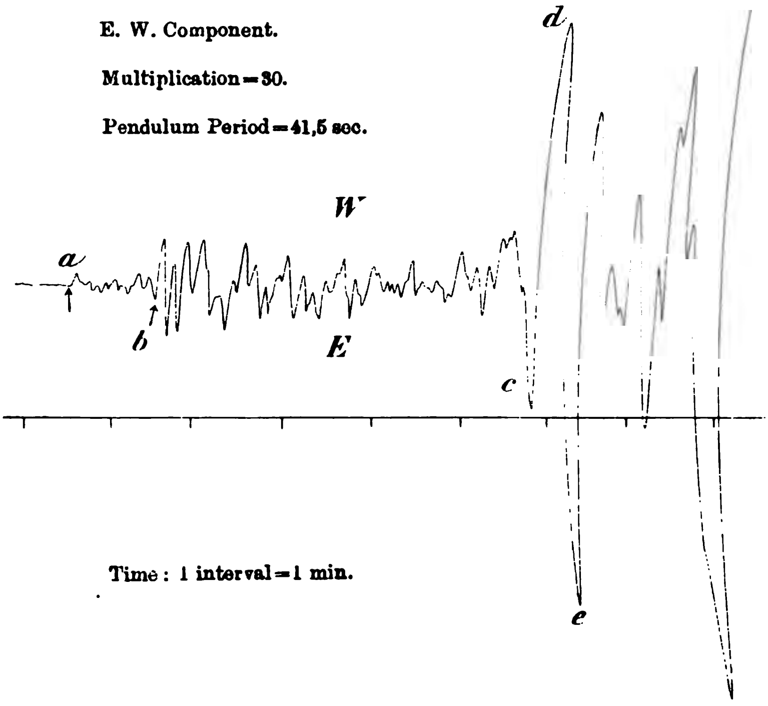
Fig. 8. Aleutian Eq., Aug. 17, 1906.

(Observed in Tokyo.)

E. W. Component.

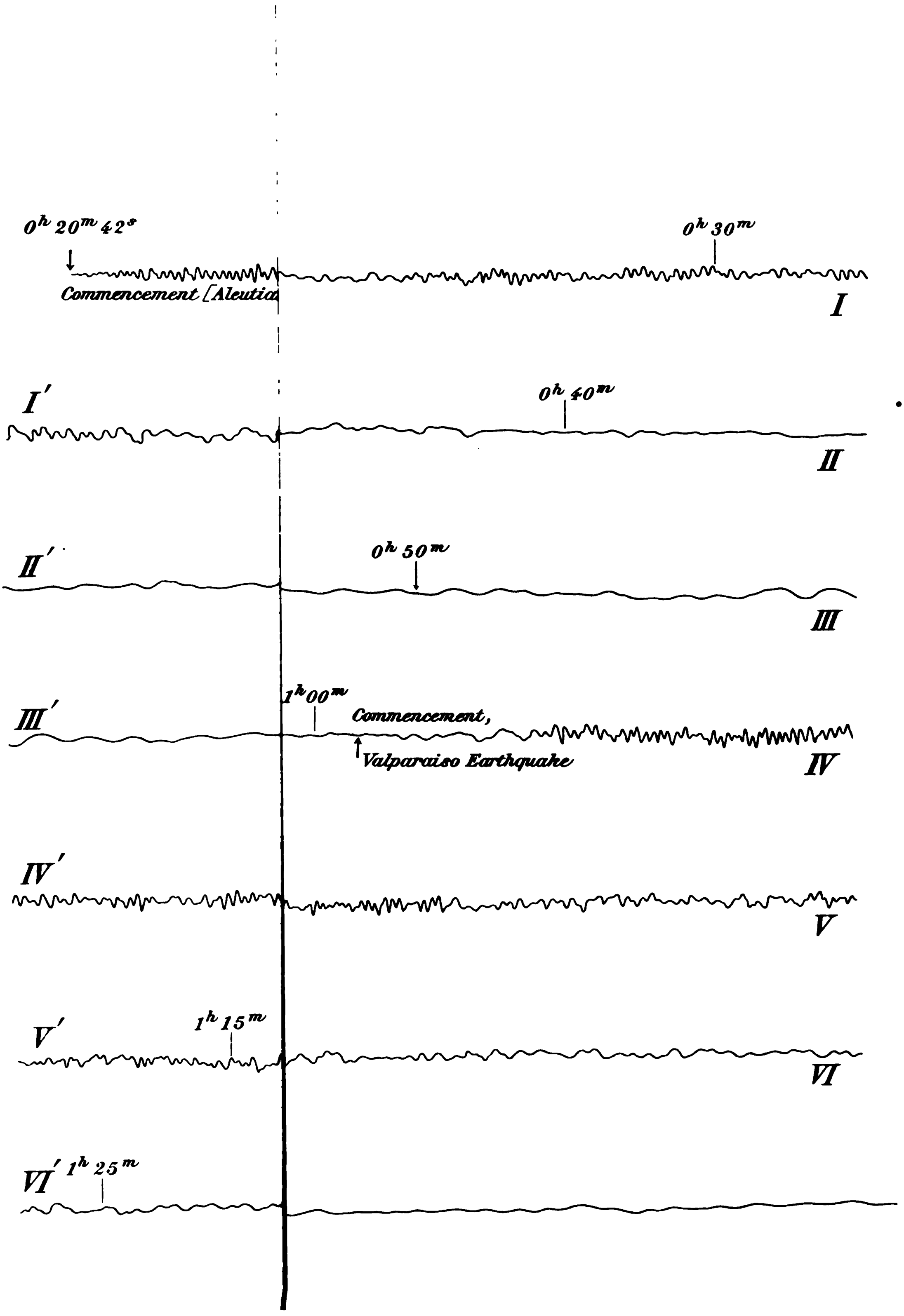
Multiplication = 30.

Pendulum Period = 41,5 sec.

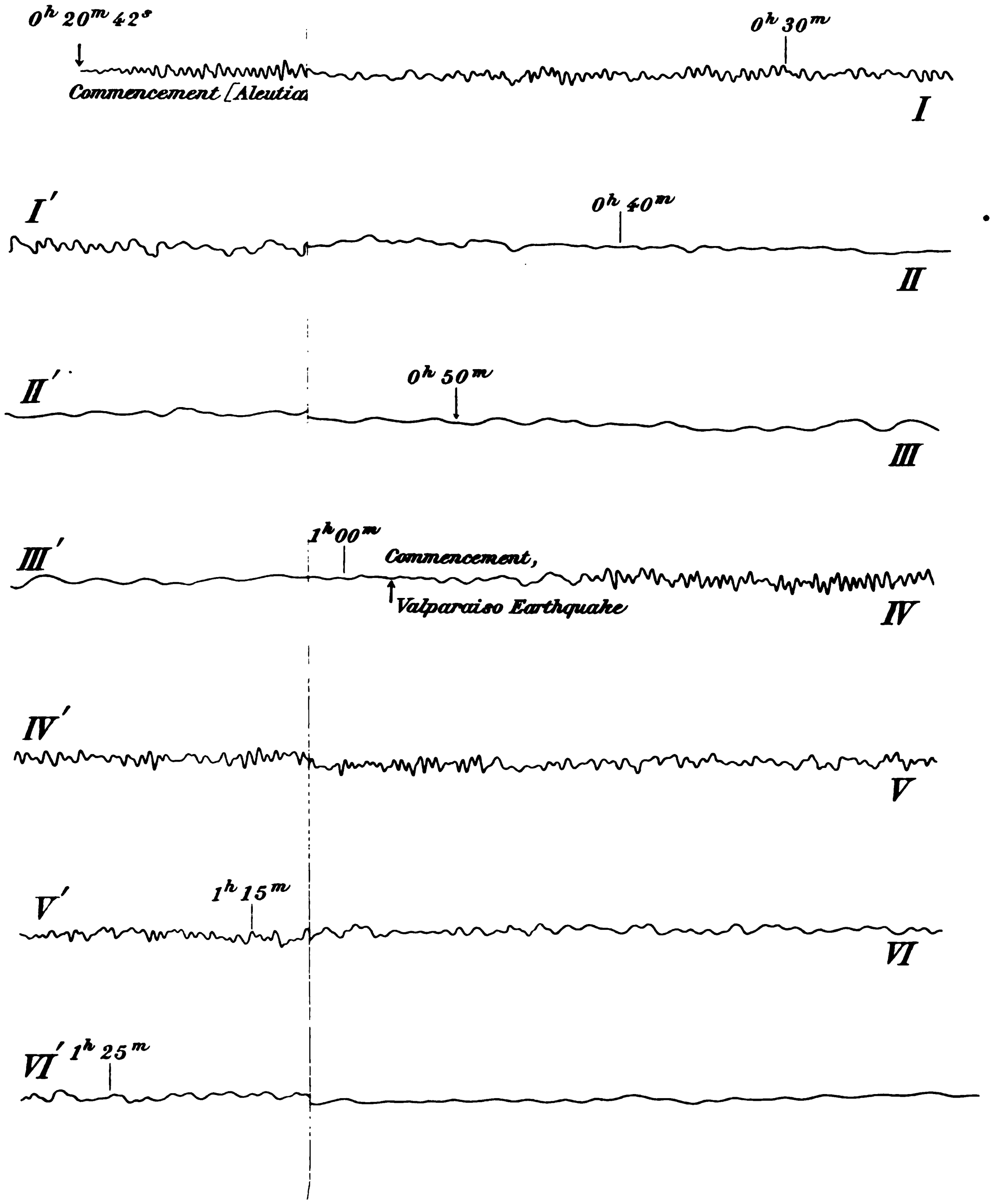


Time : 1 interval = 1 min.

906.


0h 20m 42s
Commencement [Aleutia
0h 30m
I
I′
0h 40m
II
II′
0h 50m
III
III′
1h 00m
Commencement,
Valparaiso Earthquake
IV
IV′
V
V′
1h 15m
VI
VI′
1h 25m

906.


$0^h\ 20^m\ 42^s$
Commencement [Aleutia
$0^h\ 30^m$
I
I′
$0^h\ 40^m$
II
II′
$0^h\ 50^m$
III
III′
$1^h\ 00^m$
Commencement,
Valparaiso Earthquake
IV
IV′
V
V′
$1^h\ 15^m$
VI
VI′
$1^h\ 25^m$

$T=20.3$ sec., $2a=0.14$ mm.

Then the motion became larger, the two first movements being as follows :—

$$\begin{cases} \text{(i)} & a=0.24 \text{ mm, toward S.} \\ \text{(ii)} & 2a=0.38 \text{ ,, ,, } N. \end{cases}$$

The T in the subsequent part was 7.9 sec., there being also some small vibrations of $T=3.9$ sec., $T=18.4$ sec.

Principal Portion. For the first $1^m\ 40^s$, the motion was small comparatively and had a period of $T=30.7$ sec., the three initial displacements being as follows :—

$$\begin{cases} \text{(i)} & a=0.43 \text{ mm, toward S.} \\ \text{(ii)} & 2a=1.3 \text{ ,, ,, N.} \\ \text{(iii)} & 2a=1.4 \text{ ,, ,, S.} \end{cases}$$

At the end of this epoch there took place a vibration consisting of the two following displacements :—

$$\left.\begin{cases} \text{(i)} & a=2.2 \text{ mm, toward N.} \\ \text{(ii)} & 2a=6.35 \text{ ,, ,, S.} \end{cases}\right\} \ldots\ldots T=33.8 \text{ sec.}$$

The next motion was still greater and the pointer went out of the smoked paper, toward N. Later on the pointer again entered on the smoked paper, the vibrations in the end portion of the *Chilian earthquake* being as follows :—

$$\begin{cases} T=19.6 \text{ sec.,} & 2a=0.55 \text{ mm.} \\ T=15.3 \text{ ,,} & 2a=0.20 \text{ ,,} \\ T=10.4 \text{ ,,} & 2a=0.05 \text{ ,,} \\ T=22.9 \text{ ,,} & \text{(small).} \end{cases}$$

5. *Observations at Osaka Meteorological Observatory.*

(i) **EW Component.** Fig. 4, Pl. XXIII.

The record was taken by an Omori Horizontal Pendulum Apparatus of portable form, whose instrumental constants are as follows :—

Vertical distance between the points of suspension and of support =86 cm.
Length of the horizontal strut=44 cm.
Weight of the heavy bob=16 kgm.
Period of the free oscillation=27 sec.
Multiplication of the pointer=20 times.

Aleutian Earthquake. Commencement=$0^h\ 16^m\ 52^s$.

Preliminary Tremor. Duration=$5^m\ 36^s$. The motion began quite sharply, the initial displacement being 0.04 mm, toward W. During the first $1^m\ 0^s$, the motion was small :—

$$T=5.5 \text{ sec.,} \qquad 2a=0.055 \text{ mm.}$$

The subsequent motion consisted of several sets of vibrations, as follows :—

	$T=$ 3.6 sec.,	$2a=0.055$ mm.
	$T=$ 9.5 „	$2a=0.08$ „
(?)	$T=$ 5.8 „	$2a=0.13$ „
(?)	$T=$ 33.8 „	$2a=0.23$ „

Principal Portion. The two initial displacements were as follows :—

(i) $a=0.45$ mm, toward E.
(ii) $2a=1.25$ „ „ W.

During the first $2^m\ 20^s$, the motion was small :—

$T=27.5$ sec., $2a=3.3$ mm. (Pend. Oscilns ?)

For the next $5^m\ 22^s$, the motion consisted of 11 gradually increasing pendulum oscillations :—

$T=29.4$ sec., $2a=11.2$ mm. (10th vibration);

The 1st vibration being as follows :—

$\begin{cases} \text{(i)} & a=1.35 \text{ mm, toward E.} \\ \text{(ii)} & 2a=3.05 \text{ ,, ,, W.} \end{cases}$

The subsequent motion became suddenly smaller, the vibrations during the successive epochs being as follows :—

(i) $5^m\ 55^s$....................	$T=19.2$ sec.,	$2a=2.15$ mm.
	$T=35$,,	
(ii) $7^m\ 16^s$....................	$T=20.4$ sec.,	$2a=0.78$ mm.
	$T=15.0$,,	$2a=1.25$,,
	$T=10.3$,,	$2a=0.48$,,
(iii) $5^m\ 29^s$....................	$T=16.1$ sec.,	$2a=0.53$ mm.
(iv) $12^m\ 02^s$....................	$T=15.9$ sec.,	$2a=0.25$ mm.
	$T=11.9$,,	$2a=0.13$,,

Then there appeared the earthquake motion due to the Valparaiso disturbance.

Valparaiso Earthquake. Commnecement$=1^h\ 00^m\ 15^s$.

1st Preliminary Tremor. Duration$=15^m\ 48^s$. The commencement is well marked by the appearance of small regular vibrations of $T=2.4$ sec., superposed by the following movements :—

$\begin{cases} & T=13.5 \text{ sec.,} & 2a=0.21 \text{ mm.} \\ (?) & T=6.3 \text{ ,,} & \text{(small).} \end{cases}$

At $1^h\ 09^m\ 47^s$, or $9^m\ 32^s$ after the commencement of this phase,

there was again some slight predominance of quick vibrations, which were probably the major arc propagation, the movements being as follows :—

$$\begin{cases} T=15.5 \text{ sec.}, & 2a=0.14 \text{ mm.} \\ T=\ 3.9\ \text{,,} & \end{cases}$$

2nd Preliminary Tremor. Commencement$=1^h\ 16^m\ 03^s$. Duration$=24^m\ 25^s$. During the first $9^m\ 3^s$, the motion was as follows :—

$$\begin{cases} T=12.0 \text{ sec.}, & 2a=0.13 \text{ mm.} \\ T=\ 8.0\ \text{,,} & \text{,,}\ =0.09\ \text{,,} \\ T=22.3\ \text{,,} & \text{,,}\ =0.22\ \text{,,} \end{cases}$$

there being at first traces of 3 slow (doubtful) movements of $T=2^m\ 17^s$. Then the amplitude slightly increased, there being, during the next $3^m\ 5^s$, 5 vibrations :—

$$T=37.0 \text{ sec.}, \qquad 2a=0.33 \text{ mm};$$

these were mixed with small vibrations of $T=10.9$ sec. For the next $3^m\ 30^s$, the motion was small :—

$$\begin{cases} T=12.4 \text{ sec.}, & 2a=0.075 \text{ mm.} \\ T=38.2 \text{ sec.}, & \text{(small).} \end{cases}$$

For the next $2^m\ 38^s$ there appeared again 5 large vibrations :—

$$T=31.7 \text{ sec.}, \qquad 2a=0.35 \text{ mm.}$$

During the remaining $6^m\ 28^s$, the motion was smaller :—

$$\begin{cases} T=27.7 \text{ sec.}, & 2a=0.14 \text{ mm.} \\ T=10.0\ \text{,,} & 2a=0.12\ \text{,,} \\ T=12.4\ \text{,,} & 2a=0.07\ \text{,,} \end{cases}$$

Principal Portion. Commencement$=1^h\ 40^m\ 24^s$. [1st and 2nd phases.] Duration$=13^m\ 53^s$. The motion began with 2 slow vibrations :—

$T=55.0$ sec., $2a=0.18$ mm.

The subsequent motion was smaller :—

$$\begin{cases} T=19.1 \text{ sec.,} & 2a=0.09 \text{ mm.} \\ T=10.4 \ \text{,,} & 2a=0.09 \ \text{,,} \\ \text{(?)}\ T=67.4 \ \text{,,} & \end{cases}$$

[3rd phase, etc.] Commencement$=1^h\ 54^m\ 21^s$. The motion was most active for the first $7^m\ 8^s$:

$T=23.2$ sec., $2a=1.29$ mm.

The subsequent motion was smaller, the vibrations during the successive epochs being as follows.

(i) For $7^m\ 32^s$:—$\begin{cases} T=18.3 \text{ sec.,} & 2a=0.28 \text{ mm.} \\ \text{(?)}\ T=45.0 \ \text{,,} & \end{cases}$

(ii) For the next $4^m\ 55^s$, there was a maximum group :—

$T=17.4$ sec., $2a=0.54$ mm.

(iii) For the next $7^m\ 55^s$, the motion was nearly uniform :—

$$\begin{cases} T=17.4 \text{ sec.,} & 2a=0.36 \text{ mm.} \\ T=15.9 \ \text{,,} & \text{,,} =0.11 \ \text{,,} \\ T=35.2 \ \text{,,} & \text{,,} =0.20 \ \text{,,} \end{cases}$$

During the next $26^m\ 30^s$, the motion was more or less active and comprised a series of maximum groups, which occurred at an average interval of $4^m\ 48^s$; the elements of motion in the successive maxima being as follows :—

1st max. group............$\begin{cases} T=20.3 \text{ sec.,} ......2a=0.36 \text{ mm.} \\ T=12.8 \ \text{,,} \ ......2a=0.075 \ \text{,,} \end{cases}$

2nd ,, ,, ...$\begin{cases} T=22.7 \ \text{,,} \ ......2a=0.44 \text{ mm.} \\ T=17.8 \ \text{,,} \ ......2a=\text{(small).} \end{cases}$

3rd ,, ,, ...$\begin{cases} T=23.8 \ \text{,,} \ ......2a=0.30 \text{ mm.} \\ T=18.8 \ \text{,,} \ ......2a=0.10 \ \text{,,} \ . \end{cases}$

Valparaiso Earthquake. Commencement$=1^h\ 00^m\ 15^s$. The commencement was marked by the appearance of quick vibrations, the motion being small for the first $1^m\ 6^s$. Then, at $1^h\ 01^m\ 21^s$, there appeared most active quick movements, which remained nearly uniform for the next $4^m\ 33^s$:—

T=5.7 sec., $2a$=2.4 mm.

The quick vibrations were indicated distinctly till about $2^h\ 19^m$, and slightly till $2^h\ 29^m$, there being superpositions of slow movements :—

T=2.3 sec.,....................$2a$=2.0 mm.
T=5.3 sec.; 7.4 sec.; 11.6 sec.; 14.6 sec.

At $1^h\ 07^m\ 06^s$ there was some increase in the amplitude of the quick vibrations (max. $2a$=2.0 mm.), which were probably the major arc propagation.

7. *Observation at the Querce Observatory, Florence.* The following is a note on the lithographic reproduction of the diagrams* obtained at the Querce Observatory, Florence, by a pair of Stiattesi Horizontal Pendulums, whose instrumental constants are :—

Multiplication of the pointer=25.
Weight of the heavy mass=250 kgm.
Mean velocity of the record-receiver=97 cm. per hour.
(Complete) period of free pendulum oscillation=19.6 sec.

to record small local shocks. Each of the two horizontal component pendulums has a bob of 16 kgm weight, and an oscillation period of about 2 sec., the multiplication ratio being 45.*

The times of commencement of the Aleutian and the Valparaiso earthquakes as recorded by the tremor-recorder were 0^h 17^m 17^s and 1^h 01^m 08^s (G.M.T.) respectively.

NS Component.

Aleutian Earthquake. The preliminary tremor lasted 5^m 30^s, during which the motion was most active and consisted of the following vibrations :—

$$\begin{cases} T=1.9 \text{ sec.,} & 2a=0.062 \text{ mm.} \\ T=5.4 \text{ ,,} & \text{,,} =0.038 \text{ ,,} \end{cases}$$

The movements during the earlier parts of the principal portion were as follows :—

(i) For the 1st 2^m 37^s :—

$$T=6.4 \text{ sec.,} \qquad 2a=0.04 \text{ mm.}$$

(ii) For the next 2^m 59^s :— there were 6 slow and nearly uniform vibrations mixed with quick ones :—

$$\begin{cases} T=29.8 \text{ sec.,} & 2a=0.022 \text{ mm.} \\ T=\ 5.3 \text{ ,,} & \text{,,} =0.029 \text{ mm.} \end{cases}$$

The subsequent vibrations gradually diminished and were as follows :—

$$T=13.8 \text{ sec.,} \qquad 2a=0.022 \text{ mm.}$$

Valparaiso Earthquake. The commencement was indicated by small vibrations of $T=0.92$ sec.

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* This is exactly similar to the instrument which I have described in the *Publications*, No. 18, the only modification being the use of a cylinder for the recording surface.

EW Component.

Aleutian Earthquake. The preliminary Tremor :—

$T=2.3$ sec., $2a=0.067$ mm.

The movements in the successive parts of principal portion were as follows :—

(i)	For the 1st $1^m\ 49^s$	:—$T=$ 5.0 sec.,	$2a=0.022$ mm.
(ii)	„ „ next 2 02	:—$T=30.5$ „	$2a=$ (Small).
(iii)	„ „ „ 2 12	:—$T=22.0$ „	
(iv)	„ „ „ 3 50	:—$T=17.7$ „	

The motion in the E W component was much smaller than in the NS compouent. This may be due to some unequality in the friction existing between parts of the two horizontal pendulums.

Valparaiso Earthquake. During the first 55 sec., the motion was small. Then the vibrations became most active :—

$T=2.2$ sec., $2a=0.033$ mm.

$9^m\ 10^s$ after this maximum there was another slight one, which may correspond to the major arc propagation.

6. *Observation at Manila.* Pl. XXVI. ENE-WSW Component.

The record was obtained by a Vicentini seismograph. In the following analysis, the amplitude is given *unreduced*, or not divided by the multiplying ratio of the pointer.

Aleutian Earthquake. Commencement$=0^h\ 20^m\ 42^s$. For the first $5^m\ 49^s$, the motion consisted of quick vibrations :—

$\begin{cases} T=2.4 \text{ sec.,} & 2a=3.5 \text{ mm (pendulum oscillation).} \\ T=4.8 \text{ ,,} & \end{cases}$

For the next $5^m\ 14^s$:—

$\begin{cases} T=3.8 \text{ sec.,} & 2a=1.5 \text{ mm.} \\ T=2.6 \text{ ,,} & 2a=1.0 \text{ ,,} \\ T=7.9 \text{ ,,} & 2a=2.0 \text{ ,,} \\ \text{(?) } T=20.8 \text{ ,,} & \end{cases}$

Thereafter the quick pendulum movements gradually decreased, till they disappeared at $0^h\ 38^m\ 20^s$; the principal vibrations being as follows :—

$\begin{cases} T=11.2 \text{ sec.,} & 2a=1.4 \text{ mm.} \\ T=17.8 \text{ ,,} & 2a=2.6 \text{ ,,} \\ T=4.7 \text{ ,,} & \text{(small)} \end{cases}$

For the next $8^m\ 25^s$:—

$\begin{cases} T=11.4 \text{ sec.,} & 2a=1.0 \text{ mm.} \\ T=7.5 \text{ ,,} & 2a= \text{(small.)} \end{cases}$

For the next $5^m\ 4^s$:—

$\begin{cases} T=20.4 \text{ sec.,} & 2a=0.9 \text{ mm.} \\ T=9.3 \text{ ,,} & \text{(small).} \end{cases}$

Then, at $0^h\ 51^m\ 49^s$, there took place 3 well defined slow vibrations :—

$T=20.9$ sec., $2a=1.5$ mm.

The subsequent motion was smaller :—

$\begin{cases} T=17.2 \text{ sec.,} & 2a=1.0 \text{ mm.} \\ T=11.8 \text{ ,,} & 2a=1.4 \text{ ,,} \end{cases}$

Valparaiso Earthquake. Commencement=$1^h\,00^m\,15^s$. The commencement was marked by the appearance of quick vibrations, the motion being small for the first $1^m\,6^s$. Then, at $1^h\,01^m\,21^s$, there appeared most active quick movements, which remained nearly uniform for the next $4^m\,33^s$:—

T=5.7 sec., $2a$=2.4 mm.

The quick vibrations were indicated distinctly till about $2^h\,19^m$, and slightly till $2^h\,29^m$, there being superpositions of slow movements :—

T=2.3 sec.,.....................$2a$=2.0 mm.

T=5.3 sec.; 7.4 sec.; 11.6 sec.; 14.6 sec.

At $1^h\,07^m\,06^s$ there was some increase in the amplitude of the quick vibrations (max. $2a$=2.0 mm.), which were probably the major arc propagation.

7. *Observation at the Querce Observatory, Florence.* The following is a note on the lithographic reproduction of the diagrams* obtained at the Querce Observatory, Florence, by a pair of Stiattesi Horizontal Pendulums, whose instrumental constants are :—

Multiplication of the pointer=25.
Weight of the heavy mass=250 kgm.
Mean velocity of the record-receiver=97 cm. per hour.
(Complete) period of free pendulum oscillation=19.6 sec.

Aleutian Earthquake. Commencement$=0^h\ 24^m\ 00^s$.

NW–SE Component.

1st Preliminary Tremor. Duration$=10^m\ 53^s$.

The motion consisted of small uniform vibrations.

2nd Preliminary Tremor. Commencement$=0^h\ 34^m\ 53^s$. Duration$=11^m\ 41^s$:—

$$T=17{,}3 \text{ sec.,} \qquad 2a=0.22 \text{ mm.}$$

Principal Portion. Commencement$=0^h\ 46^m\ 34^s$. [1st and 2nd phases] Duration$=13^m\ 30^s$. For the first $7^m\ 47^s$, the motion consisted of slow vibrations :—

$$T=36.0 \text{ sec.,} \qquad 2a=0.36 \text{ mm.}$$

Then there set in large pendulum oscillations, which continued till $2^h\ 27^m$, thereby confusing the movements due to the Valparaiso earthquake. These oscillations were as follows :—

$$T=18.1 \text{ sec.,} \qquad 2a=6.9 \text{ mm. (pend. oscillation).}$$

NE–SW Component.

In this component diagram the pendulum oscillations were much smaller than the other.

1st Preliminary Tremor. Duration$=10^m\ 32^s$.

The vibrations were very small.

2nd Preliminary Tremor. Duration$=12^m\ 6^s$:—

$$T=\ 9.7 \text{ sec., } 2a=0.10 \text{ mm.; } T=14.6 \text{ sec.}$$

8. *Summary of the Observations of the Aleutian Earthquake.* The mean values of the different periods of vibrations, which occurred at Tokyo, Osaka, Manila, and Querce, are given in the following table, the periods most frequently occurring being printed in fat characters.

Periods of Vibration.

Tokyo. (EW)	Tokyo. (Vertical)	Tokyo. (NS)	Osaka. (EW)	Osaka. Horiz. Tremor Recorder.	Manila.	Querce.	*Mean.*
sec.	sec.	sec.	sec.		sec.	sec.	sec.
—	3.5	—	—	1.9 (pend. 2.3 oscl.)	2.9	—	—
4.7	4.6	4.5	5.0	5.5	4.8	—	4.7
6.4	—	—	—	—	—	—	—
8.6	9.4	—	—	—	8.2*	9.7	8.8
10.7	11.5	—	10.6	—	11.5	—	11.1
—	—	—	—	13.8	—	—	13.8
18.8*	16.5	18.4	15.9	17.7	17.5*	17.7(P.O.)*	17.4
—	—	20.3	20.0*	—	20.7*	—	20.3
—	22.3*	—	—	22.0	—	—	22.2
26.1*	—	—	28.5(P.O.)*	—	—	—	27.3
30.9	—	30.7	—	30.2	—	—	30.6
36.0*	34.0*	33.8*	34.4	—	—	36.0*	34.8

It will be seen from the above table amongst others that the (mean) periods of 4.7 sec., 8.8 sec., 11.1 sec., 17.4 sec., 20.3 sec., 22.2 sec., 30.6 sec., and 34.8 sec. occurred at Tokyo as well as at one or more of the three other places, namely, Osaka, Manila, and Querce. (See also § 15.) The Tokyo records indicate that there was no special difference in the periods of vibration between the horizontal and vertical movements.

In the following table are collected the times of earthquake occurrence at the above mentioned four places, and at 25 other stations ; the data relating to the latter having been taken from the monthly or weekly reports published by the different seismological observatories. In a few cases, the time of occurrence of the 2nd preliminary tremor and the duration of the 1st preliminary tremor are also given.

* The periods of the predominating vibrations are marked with *asterisks*.
(P.O.) marks the pendulum oscillations.

OBSERVATION OF THE ALEUTIAN EARTHQUAKE.

(Time in G.M.T.)

Place.	Position.		Time of occurrence $=t_1$	Time of commencement of 2nd P. T. $=t_3$	Duration of the 1st Preliminary Tremor.
	Latitude.	Longitude.			
Origin......... *	50° N	175° E	0^h 11^m 44^s		
Tokyo............	35° 42′ 29″ N	139° 45′ 53″ E	0^h 17^m 16^s		(Total P.T.) 5^m 20^s
Osaka	34 42 — N	135 31 — E	0 16 52		5 36
Mizusawa	39 08 — N	141 07 — E	0 16 57		
Taihoku (Formosa)	35 02 — N	121 30 — E	0 20 07		
Manila	14 34 41 N	120 58 33 E	0 20 42		
Zikawei	31 11 33 N	121 10 45 E	0 19 59		
Berkeley, Cal...	37 52 24 N	122 15 11 W	0 18 00		
Washington D.C...	38 54 18 N	77 03 06 W			
Göttingen	51 33 — N	9 58 — E	0 23 43	0 32 30	8 47
Strassburg	48 35 00 N	7 46 10 E	0 23 01	———	13 33(?)
Heidelberg	49 23 55 N	5 58 44 E	0 23 08		
Budapest	47 22 29 N	19 03 55 E	0 23 34		
O'Gyalla	47 52 24 N	18 52 32 E	0 22 42		
Zagreb	45 48 54 N	15 58 48 E	0 23 23		
Kremsmünster.....	48 03′ — N	14 08′ — E	0 23 23	0 32 55	9 32
Laibach	46 03′ — N	14 31′ — E	0 23 37	0 34 08	10 31
Vienna	48 15′ — N	16 22′ — E	0 22 41	0 37 36	
Triest	45 39′ — N	13 46′ — E	0 23 25		
Tiflis	41 43 08 N	44 47 51 E	0 22 54		
Borshom	41 51 — N	43 23 08 E	0 23 45		
Achalkalaki	41 25 — N	43 29 09 E	0 23 49		
Upsala	59 51 30 N	17 37 30 E	0 22 00		
Belgrad	44 48′ — N	20 09′ — E			
San Fernando (Spain)..........	36 27 40 N	6 12 19 W	0 23 24		
Tortosa	40 49 — N	2 34 — E	0 23 21		
Coats Observatory (Paisley).........	55 51 — N	4 25 — W	0 31 36		
Querce (Florence)..	43 47 18 N	11 16 42 E	0 24 00		
Ximeniano (")...	43 46 40 N	11 15 24 E	0 24 00	0 35 30	11 30

* The position of the origin has been determined by methods given in § 9. For the determination of the time of earthquake origin see § 11.

9. *Determination of the Approximate Position of the Origin of the Aleutian Earthquake.* The approximate position of the earthquake origin may be determined in two different ways, from seismographic observations made at a number of stations, as follows :—

(i) By a comparison of the times of earthquake occurrence ;

(ii) From the epicentral distances deduced from the durations of the preliminary tremors.

1*st Method* : *Comparison of the times of occurrence.* As an example, let us take the times $(=t_1)$ of earthquake occurrence at Tokyo, Florence, Manila, and Berkeley (California):—

Tokyo..................	$t_1=0^h$	17^m	16^s
Florence...............	$t_1=0$	24	00
Manila..................	$t_1=0$	20	42
Berkeley...............	$t_1=0$	18	00

It is evident that among the above 4 stations Tokyo was nearest to the origin. As, further, the duration of the total preliminary tremor in Tokyo was $5^m\ 20^s$, which corresponds to an epicentral distance of about 25°, I shall assume a propagation velocity of 13^{km} per sec. for the differential epicentral distances between Tokyo, Berkeley, and Florence (Ximeniano and Querce.) For the comparison of Tokyo and Manila, however, let us take a somewhat lower velocity, say, 10^{km} per sec. Under these suppositions, we obtain the following results :—

Combination of places.	Difference of times of commencement.		Approximate Epicentral Difference.
Florence-Tokyo............	6^m	44^s	47.°3
Manila-Tokyo...............	3	26	24.3
Berkeley-Tokyo...........	0	44	5.2

A circle drawn about Manila as centre with a radius of 24.°3 passes very nearly through Tokyo, while the locus of equidistanc between Tokyo and Florence intersects that between Tokyo and San Francisco at about $\varphi=57°$ N, $\lambda=179°$ W ; this latter point, or the epicentre, being situated, nearly in the same great circle which connects Tokyo and Manila.

2*nd Method* : *Comparison of the epicentral distances deduced from the duration of the preliminary tremor.* The relation of the epicentral distance (x) to the duration (y_1) of the 1st preliminary tremor, or the total duration (y) of the 1st and 2nd preliminary tremors, is approximately given by either of the two following equations*

$$\begin{cases} \overset{\text{km.}}{x} = 17.1 \ \overset{\text{sec.}}{y_1} - \overset{\text{km.}}{1360}. \\ x = 6.54\, y + 720. \end{cases}$$

Taking the observations at Tokyo and Florence, (Ximeniano) for instance, we have :—

$$\begin{cases} \text{Tokyo} \ldots\ldots\ldots\ldots\ldots\ldots y = 5^m\ 20^s; \quad x = 25°.3 \\ \text{Florence} \ldots\ldots\ldots\ldots\ldots y_1 = 11\ \ 30\ ; \quad x = 94. \end{cases}$$

If two circles be drawn about Tokyo and Florence as centres, with the radii of 25°.3 and 94° respectively, they intersect at about $\varphi=44°$ N, $\lambda=170°$ E.

Taking the mean of the two positions above obtained, we find, for the approximate situation of the earthquake origin,

$$\lambda = 50° \text{ N}, \qquad \varphi = 175° \text{ E}.$$

The epicentral distances of some of the observing stations are as follows :—

Tokyo..........................	29°	08′
Osaka...........................	32	26
Berkeley........................	45	22
Manila..........................	58	25
Florence........................	85	09

* The "Publications," No. 5 and No. 13.

10. ***Aleutian Earthquake: Direction of Motion in Tokyo.*** From a comparison of the descriptions of the EW and NS component diagrams (**iii** and **iv**, § **4**), we see that the displacement occurring at the very commencement of the earthquake was as follows:—

$$\begin{cases} 0.04 \text{ mm, towards W,} \\ 0.06 \text{ „ , „ S;} \\ \text{Resultant motion} = 0.07 \text{ mm, towards S } 34^\circ \text{ W.} \end{cases}$$

Again the two displacements constituting the first vibration of the principal portion were as follows:—

$$\text{(i)}\ldots\ldots\begin{cases} 0.25 \text{ mm, towards W,} \\ 0.24 \text{ „ , „ S;} \\ \text{Resultant motion} = 0.34 \text{ mm, towards S } 46^\circ \text{ W.} \end{cases}$$

$$\text{(ii)}\ldots\ldots\begin{cases} 0.43 \text{ mm, towards E,} \\ 0.38 \text{ „ , „ N;} \\ \text{Resultant motion} = 0.57 \text{ mm, towards N } 49^\circ \text{ E.} \end{cases}$$

Taking the mean of these three results, we find that the direction of motion was

$$\text{S } 48^\circ \text{ W}^\circ - \text{N } 48^\circ \text{ E.}$$

This direction points very nearly towards the source of the earthquake disturbance located from the seismographic observations (§ 9), the actual direction of the centre from Tokyo being N 50° E. It will be observed that the initial or first displacement of vibration was directed away from the origin.

11. ***Determination of the Approximate Time of Occurrence at the Origin of the Aleutian Earthquake.*** The approximate time ($=t_0$) of earthquake occurrence at the origin can be estimated by means of the following equation*:—

$$t_0 = t_1 - 1.165\, y_1^{\text{sec.}}$$

* The *Bulletin*, No. 1.

in which t_1 and y_1 are respectively the time of occurrence and the duration of the 1st preliminary tremor at any given station. Applying, for instance, the above formula to the observations made at Göttingen, Ximeniano, and Laibach, we obtain the following results:—

Göttingen .... $\begin{cases} t_1 = 0^h 23^m 43^s; \; y_1 = \;\, 8^m 47^s \\ t_0 = 0^h 13^m 28^s \end{cases}$

Ximeniano............ $\begin{cases} t_1 = 0 \; 24 \;\; 00\,; \; y_1 = 11^m 30^s \\ t_0 = 0 \; 10 \;\; 35 \end{cases}$

Laibach................ $\begin{cases} t_1 = 0 \; 23 \;\; 37\,; \; y_1 = 10^m 31^s \\ t_0 = 0 \; 11 \;\; 19 \end{cases}$

Taking the mean of the above three values of the t_0, we find:—

t_0, or time of earthquake commencement $= \mathbf{0^h 11^m 44^s}$

12. ***Valparaiso Earthquake.*** According to newspaper reports, the Valparaiso earthquake happened a short time before 8 o'clock in the evening, of the 16th of August. As shown in § 13, the approximate time of occurrence in the epicentral district was probably $0^h 40^m 05^s$ (the 17th) in Greenwich Mean Time, or $7^h 53^m 29^s$ P.M. (the 16th) in the Valparaiso Local Time. At Valparaiso the weather on the day of the earthquake was unusually calm and pleasant.*

The earthquake and subsequent fires produced a considerable amount of damage in the city of Valparaiso; the shock having also caused a great destruction in Vina del Mar, Le Ligna, Limache, Quilque, Arriaca, Palequin, Meripilla, Quillota, Llaillai, Hierro

* A fine and calm weather, which generally corresponds to the rise of the barometric pressure, also characterized most of the great destructive earthquakes in Japan.

Viejo, Aberca, Conchall, Petarda, La Placilla, La Calera, Los Andes, San Felipe, and some other places. There were 30 deaths in the city of Santiago, while the town of Vallenar (300 miles north of the capital) is said to have been badly affected.

The strong motion area seems to have extended from Vallenar on the north to Santiago on the south, over a distance of about 300 miles. The earthquake origin was probably an elongated sub-oceanic zone parallel to the coast, the most central part of which may be assumed *roughly* to be at about 250 km to the NNW of Valparaiso, or at the following position:—

$$\varphi=31^{\circ}\ \mathrm{S}, \qquad \lambda=73^{\circ}\ \mathrm{W}.$$

According to a letter of Dr. Ricardo Poenisch, of Santiago, there was no surface manifestation of faults, but apparently the coast was elevated more than 1 metre. The shock was felt on the north as far as Tacna, the northern-most province of Chile, at a distance of about 450 miles from Valparaiso.

The epicentral distances of the different stations, where the distinct commencement of the Valparaiso earthquake was observed, are as follows:—

Tokyo	152° 22′
Osaka	155 51
Göttingen	109 46
Ximeniano	107 07
Manila	159 10

13. ***Observation of the Valparaiso Earthquake.*** The time (t_1) of occurrence observed at the different stations were as follows:—

Tokyo	$t_1 = 1^h 00^m 34^s$
Osaka	1 00 15
Mean	**1 00 25**
Manila	1 00 15
Göttingen	1 13 30 (?) (Vert. Seismograph.)
Ximeniano	0 58 15

The durations (y_1 and y_2) of the 1st and 2nd preliminary tremors were as follows:—

Tokyo	$y_1 = 18^m 59^s$;	$y_2 = 26^m 05^s$;	$y_1 + y_2 = 45^m 04^s$
Osaka	$y_1 = 15\ 48$;	$y_2 = 24\ 25$;	$y_1 + y_2 = 40\ 13$
Mean	$y_1 = \mathbf{17\ 24}$;	$y_2 = \mathbf{25\ 15}$;	$y_1 + y_2 = \mathbf{42\ 39}$

Time (t_5) of commencement of the 3rd phase of the principal portion was as follows:—

Tokyo	$t_5 = 1^h 52^m 18^s$	(Vertical component)
„	1 58 53	(EW „)
Osaka	1 54 21	(„ „)
Mean	**1 55 11**	

W_2 Motion. The time intervals between the corresponding epochs in the 1st preliminary tremor of the W_1 and W_2 waves, at Tokyo, Osaka and Manila, were as follows:—

Tokyo	$6^m 35^s$ (Vertical) 7 45 (EW component)
Osaka	9 32
Manila	5 45

The identification of the W_2 motion was in each case extremely difficult, and the intervals of time above given are to be regarded only as rough estimates. Taking the mean, we obtain a time

interval of $7^m 24^s$, corresponding to a mean epicentral distance of 155° 48′. The theoretical time interval corresponding to the latter value of the epicentral distance, would be, if we suppose a propagation velocity of 13 km per sec., equivalent to

$$\frac{360°-(2\times 155° 48')}{13}=6^m 54^s$$

14. ***Estimation of the Time (t_0) of Occurrence at the Origin of the Valparaiso Earthquake.*** Taking the mean of the Tokyo and Osaka observations, we have, according to the equation in § 11,

$$\begin{cases} t_1 = 1^h 00^m 25^s \\ y_1 = 17^m 24^s \\ t_0 = t_1 - 1{\cdot}165\ y_1 = 0^h 40^m 05^s \text{ (G.M.T.)} \end{cases}$$

Now the Valparaiso mean local time is that of longitude 71° 39′ W, or $4^h 46^m 36^s$ after G.M.T. We have, therefore,

$$t_0 = 7^h 53^m 29^s \text{ P.M. (Local time).}$$

15. ***Comparison of the Periods of Vibration in the Valparaiso Earthquake with those in the Caracas and Guatemala Earthquakes.*** The following table gives the mean values of the different periods found in the seismograms obtained at Tokyo, Osaka, and Manila, together with those found in the Tokyo seismograms of the Caracas earthquake of Oct. 29, 1900, and the Guatemala earthquake of April 19, 1902; the periods of more frequent occurrence being printed in fat characters.

Caracas and Guatemala Earthquakes.	Valparaiso Earthquake.				
Tokyo (Horizonal).	Tokyo (Horizontal).	Tokyo (Vertical).	Osaka (EW).	Manila.	*Mean.*
Sec.	Sec.	Sec.	Sec.	Sec.	Sec.
2.9	—	—	2.4	—	—
—	4.0	3.5	3.9	5.5	4.0
7.9	9.0	—	8.0	7.4	8.4
10.2	11.5	11.2	{ 10.4 12.4	11.6	11.4
14.8	15.7	—	{ 14.0 16.0	14.6	15.1
18.4	17.7	18.2	19.1	—	18.3
21.2	22.3	22.4	23.0	—	22.6
		26.8			26.8
26.9	29.7	—	27.7	—	28.7
32.9	32.7	—	31.7	—	32.4
39.5	37.7	—	36.8	—	37.1
45.4	—	—	45.0(?)	—	45.0(?)
56.0	—	—	—	—	—
—	—	—	67.4(?)	—	67.4(?)

From the above table it will be seen that the different periods of vibration, which occurred at Tokyo in the Caracas and Guatemala earthquakes, were almost perfectly identical with those which occurred at Tokyo and Osaka in the Valparaiso earthquake. The Manila seismogram indicates only shorter periods, which are also found in the Tokyo and Osaka records. It is almost certain that, if the Manila seismograph had a long natural period of oscillation, other slow periods would have been likewise registered there. It may be here mentioned that I have taken, for comparison, the

Caracas and Guatemala earthquakes, as the origins of these shocks had, with respect to Tokyo, epicentral distances and azimuths not widely different from those of the Valparaiso earthquake.

By comparing the above table with the list of periods in § 8, it will be seen that the periods of vibration in the Aleutian earthquake also occurred in the Central and South America earthquakes.

The examination of the numerous seismographic records of the great Indian earthquake of April 4, 1905, has also shown the common occurrence of various periods of vibration in different parts of the would.

From the facts like the above, it seems probable that the microseismic or unfelt and slow periods of vibration are approximately the same in different earthquakes and at different stations. I have previously stated a similar conclusion with regard to the *pulsatory oscillations.*

Sea Waves.

16. ***Tidal Disturbances due to the Valparaiso Earthquake.*** The earthquake caused some tidal disturbances, which spread over the Pacific. Thus, in the enclosed Bay of Maalaea, on the island of Maui (Hawaii) the wave is said to have reached a height of 12 feet. An inter-island steamer Noeu, while anchored off the north-eastern coast of the island of Hawaii in a calm sea was carried forward by a sudden undertow, which was so strong that her chain parted and she lost her anchor and forty fathoms of chain. It is, however, noteworthy that there were apparently no sea waves at Valparaiso itself, there being no newspaper account of such disturbances at the Chilian port. The fact seems to be that the tidal

waves in the vicinity of Valparaiso did not, owing to the great depth of the water along the coast, attain any considerable amount, failing thereby to produce damage or attract attention.

16. *The Sea Waves observed at Honolulu, San Diego and San Francisco.* The tidal disturbances due to the Valparaiso earthquake, recorded on the tide gauges at Honolulu, San Diego, and San Francisco, whose *direct* arcual distances from the origin of disturbance are respectively 96° 21′, 76° 12′, and 82° 52′, were as follows.*

Honolulu.

$\varphi = 21° 18' N$; $\lambda = 157° W.$

The time used is that of longitude 157° 30′ W, or 10^h 30^m after G.M.T.

Slight traces of disturbances appeared at about 3 A.M. (Aug. 17th), the period being 33.3^{min}. But the distinct movement began first at 5^h 15^m A.M., and remained active for the next 20 hours :—

$T = 25.5$ min., $2a = 0.28$ ft.

In the subsequent portion, (the movement continued more or less active till Aug. 19th):—

$$\begin{cases} T = 26.3 \text{ min.,} & 2a = 0.15 \text{ ft.} \\ T = 45.3 \text{ ,,} & \end{cases}$$

San Diego.

U.S. Quarantine Wharf. $\varphi = 32° 42' N$; $\lambda = 117° 10' W.$

The time is the Western States Time, or 8 hours after G.M.T.

The movement was indicated distinctly first at 6^h 30^m A.M., and remained active till about 6^h 40^m P.M. :—

* Denoting by T and $2a$ the complete period and the range, or double amplitude, of the wave motion.

$$\begin{cases} T=21.8 \text{ min.}, & 2a=0.45 \text{ ft.} \\ T=16.2 \ \ ,, & \\ T=59.1 \ \ ,, & \end{cases}$$

San Francisco.

Presidio. $\varphi=37° 48' \text{N}$; $\lambda=122° 30' \text{W}$.
Time used: The Western States Time.

The distinct movement began at $7^h\ 42^m$ A.M., remaining active till about 11^h P.M. Up to about $8^h\ 30^m$ P.M., the predominating oscillations were as follows:—

$$\begin{cases} T=59.1 \text{ mm.}, & 2a=0.28 \text{ ft.} \\ T=21.3 \ \ ,, & \end{cases}$$

Thereafter the oscillations were as follows:—

$$\begin{cases} T=41.0 \text{ mm.}, & 2a=0.28 \text{ ft.} \\ T=25.2 \ \ ,, & 2a=0.24 \ ,, \end{cases}$$

17. *The Sea Waves observed at Japanese Coasts.* The sea waves due to the Valparaiso earthquake were also recorded at the different tide-gauge stations on the Pacific coasts of Japan. The following is a short description of the mareogram obtained at Kushimoto, a small sea port situated at the southern extremity of the Kii peninsula.

(1) *Kushimoto.* $\varphi=33° 27' \text{N}$; $\lambda=135° 45' \text{E}$.
Time used is that of longitude 135° E.

The sea waves began to appear at $9^h\ 27^m$ A.M., Aug. 18th. For the first 41^m, there were two small oscillations, of T=20.5 *min.* For the next $2^h\ 49.5^m$, there were 8 oscillations of T= 21.2 *min.*, whose magnitude gradually increased, the 7th having the maximum motion of 44 *cm.* The very initial motion was directed upwards ($2a=6$ *cm.*)

For the next 4^h 25^m, the movement became smaller, the predominating period being shorter:—

$$T=11.9 \text{ mm.}, \qquad 2a=10 \text{ cm.}$$

Thereafter the movement became again larger and slower:—

$$T=22.3 \text{ mm.}, \qquad 2a=16.5 \text{ cm.}$$

(ii) *Hakodate*: $\varphi=41°\ 46'$ N; $\lambda=140°\ 44'$ E.
Ayukawa: $\varphi=38°\ 18'$ N; $\lambda=141°\ 31'$ E.
Misaki: $\varphi=35°\ 9'$ N; $\lambda=139°\ 37'$ E.

The times of commencement of the sea waves at these three places were as follows* :—

Hakodate	... ...	10.02 A.M., Aug. 18th.
Ayukawa	... ...	9.29 „ „ „
Misaki...	... ...	8.23 „ „ „

I have also examined the mareograms obtained at the stations on the Japan Sea side. But these gave no clear evidence of the existence of the sea waves due to the earthquake in question.

18. ***The Velocity of Propagation across the Pacific.*** As is well known, the propagation velocity (v or v') of sea waves may be calculated in two different ways as follows:—

$$v=\frac{s}{\delta t} \qquad (1)$$

$$v'=\sqrt{gh} \qquad (2)$$

In (1), s denote the distance between the earthquake origin and a given tide-gauge station, δt being the time interval taken by the sea waves in traversing that distance. In (2), g is the ac-

* Taken from Dr. K. Honda's paper: *On the Velocity of Sea Waves through the Pacific.* Tokyo Sugaku-Buturigakkwai Kizi-Gaiyo. Vol. III, No. 9.

celeration due to the gravity and h the mean sea depth along the distance s.*

Kushimoto. Accorning to § 11, the time of earthquake occurrence at the origin was 0^h 40^m 05 (G.M.T.). Hence :—

$$\delta t = 23^h\ 47^m.$$

The great circle connecting Kushimoto with the earthquake origin ($\varphi=31°$S, $\lambda=73°$W) is 155.°5 ($=s$) in length, passing on the whole through deeper parts of the Pacific. The mean depth h is about 4470 metres. We thus obtain:—

$$\begin{cases} v = 202 \text{ metres/sec.} \\ v' = \sqrt{gh} = 209 \text{ metres/sec.} \end{cases}$$

Honolulu. For the Honolulu observation, we have:—

$$s = 96°\ 21' \ ; \qquad \delta t = 15^h\ 05^m;$$

s being the distance along the great circle connecting Honolulu with the earthquake origin, along which the mean depth h is about 4150 metres. We have therefore:—

$$\begin{cases} v = \dfrac{s}{\delta t} = 197 \text{ metres/sec.} \\ v' = \sqrt{gh} = 201.6 \text{ metres/sec.} \end{cases}$$

In these two cases, the agreement between the velocities calculated by the two different methods are in fair agreement with one another.

San Francisco and *San Diego.* The time intervals δt for San Francisco and San Diego were respectively 15^h 02^m and 13^h 50^m. The great circles between these two places and the earthquake origin, whose lengths (s) are 82° 52′ and 76° 12′, pass very closely off the coast, the mean depths (h), measured a little outward (or

* A correction to the formula (2) has been given by Dr. C. Davison. *Phil. Mag.*, Jan. 1897.

westward) of these arcs, being respectively about 4210 and 4220 metres. We thus obtain:—

San Francisco.................. $\begin{cases} v = \dfrac{s}{\delta t} = 170 \text{ metres/sec.} \\ v' = \sqrt{gh} = 203 \quad " \quad " \end{cases}$

San Diego .... $\begin{cases} v = \dfrac{s}{\delta t} = 170 \quad " \quad " \\ v' = \sqrt{gh} = 203 \quad " \quad " \end{cases}$

In each of these two cases, the actual velocity v is much smaller than that deduced from the mean sea depth, the discrepancy being probably due to the inexactness of the assumed wave path, which runs parallel to the coast.

19. *Conclusion.* The foregoing are only fragmentary notes on the Valparaiso and Aleutian earthquakes. A fuller account of the sea waves propagated across the Pacific will be given in a future number of the "Bulletin."

Tokyo. Jan., 1907.

On the Distribution of Recent Japan Earthquakes.

By

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I. PRELIMINARY.

1. ***Arrangements of Earthquake Zones.*** Let A (Fig. 1) represent a portion of the earth's surface, which is being depressed down. Then it can easily be demonstrated that there will be formed in the surrounding region two systems of weak lines, as shown in the figure. These are, *firstly*, concentric arcs, and *secondly*, radial lines, corresponding respectively to the dislocations and the cracks in the earth's crust.

Fig. 1

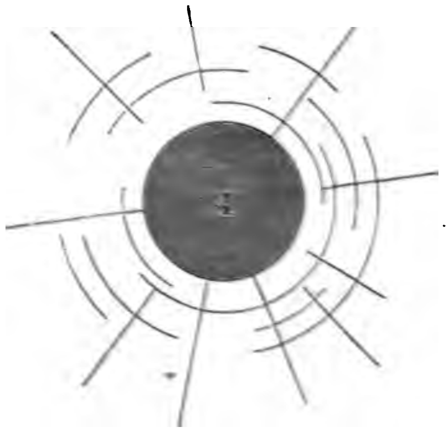
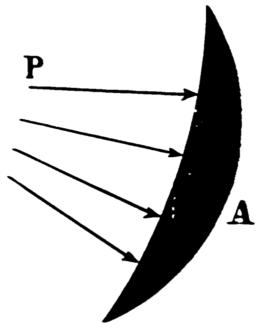


Fig. 2



Let us next vary slightly our supposition, and assume A (Fig. 2) to be a portion of the earth's surface, which is pushed from one side by a pressure P. In this case there will be formed two systems of the weak lines, similar to those mentioned above ; the

concentric lines, however, becoming in this case foldings in the earth's crust. One of the consequences of the existence of the horizontal pressure P is that the outer (or convex) and the inner (or concave) sides of the region under consideration differ materially in the topographical features ; the former being much steeper in gradient than the latter. (See also Fig. 4). A may be a great mountain chain or a series of islands, arranged in a curvilinear form.

2. *Japanese Islands.* Fig. 2 is a diagrammatic representation of the Japanese islands, which, as shown in Fig. 3, forms a circular arc, whose convex and concave sides are turned toward the Pacific Ocean and Japan Sea respectively ; a glance at any map of Japan suggesting the idea that the islands were caused to assume their curvilinear form by the pressures acting from the Japan Sea side. The difference in the steepness of the gradient between the two sides of the island arc of Japan is illustrated in Fig. 4, which gives an ideal cross section of the latter.

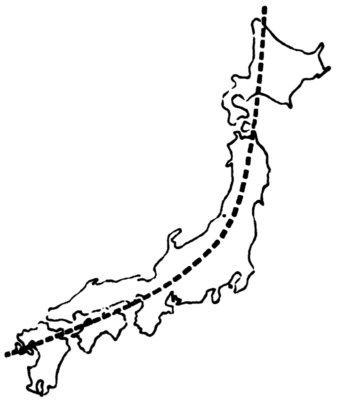
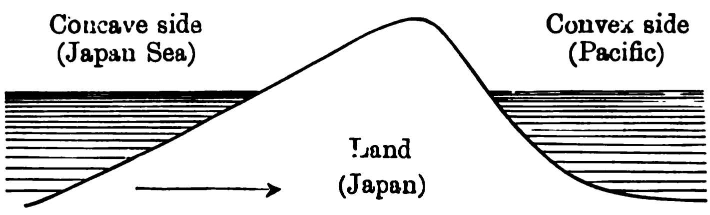


Fig. 3

The dotted line shows the general curve form of Japanese islands.

Fig. 4



As is well known, the Japan Sea is shallow and its greatest depth is only 3000 metres ; the gradient of the sea bottom, which is shallow, varying from 1 in 67 (off the coasts of Uzen and Ugo) to 1 in 110 (off the coasts of San-in Do provinces). The average gradient to the basin of 1000 metre depth from the west coasts of Hokkaido is 1 in 220. On the other hand, the Pacific Ocean is very deep, the Tuscarora basin, which lies off the northeastern coasts of Japan, reaching the depth of over 8000 metres at distances of 180 to 380 ^{km} from the coasts. The gradient of the Pacific bottom is much steeper than in the case of the Japan Sea, being, for example, as follows :—

Off the coast of Nemuro	1 in 27
„ NE „ „ Main Island	1 in 30
„ coast of Kii (to 5000 metres depth)	1 in 24
„ „ „ Tosa („)	1 in 32
„ SE coast of Kazusa and Awa (to 3000 metres depth) ...	1 in 16

3. ***Himalayas.*** The Himalayan mountain ranges furnish also a good example of the relation between the curvature and the steepness of the gradient, and form, as diagrammatically shown in

Fig. 5.
Showing the general course of the Himalayas.

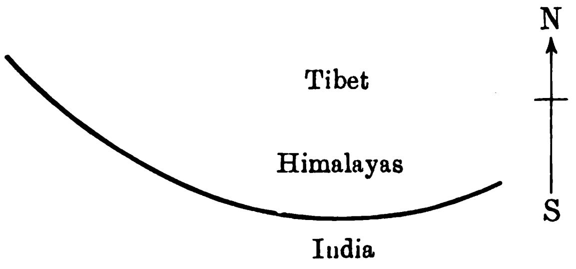


Fig. 5, a very beautiful circular arc extending in an east-west direction. The convex, or southern, side is very steep, the great mountains rising almost abruptly from the flat plane grounds of

India. On the other hand, the concave, or northern, side is not steep, constituting the plateau of Tibet.

4. *Sumatra and Java.* The two islands of Sumatra and Java also form together an arc, as indicated by the dotted curve in Fig. 6. The sea on the concave, or north-eartern, side is shallow (under 200 metres), while that on the convex, or south-western side is much deeper (over 5000 metres); it being also noteworthy that, in the case of Sumatra, mountain ranges lie close to the convex side.

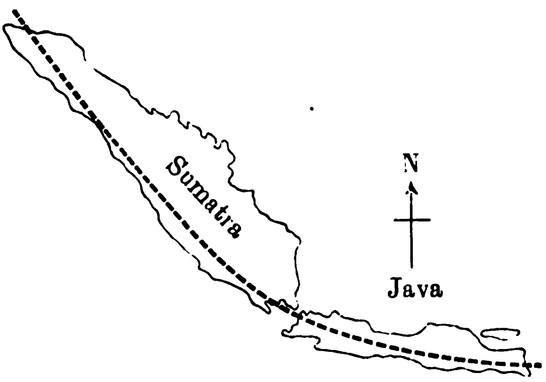


Fig. 6.
The dotted line indicates the general curvature of the two islands of Sumatra and Java.

5. *Aleutian Islands.* The Aleutian islands form a regular arc stretching in an east-west direction. Here again, the sea on the convex (southern) side is much deeper than that on the concave (northern) side. (See the preceding Article.)

6. *Relation between the Curvature and the Seismic Activity.* In simple cases, like those above mentioned in which there is a regular arc of mountain ranges or series of islands, the convex side is often shaken by great earthquakes, while the concave side is disturbed only by occasional local shocks.

7. *Distribution of Destructive Earthquakes in Japan.** The origins of the 221 destructive earthquakes of Japan proper,

* A very valuable investigation on the distribution of small Japan earthquakes of recent years has been given by Count F. de Montessus de Ballore in *Archives des Sciences Phys. et Nat.* 1897.

which happened between the 5th century and the present time, were approximately as follows:—

Inland origins	114
Pacific „	47
Japan Sea origins	17
Inland Sea „	2
(*unknown*	41)

Again, among the above-mentioned 224 earthquakes, there were 10, which were very extensive and violent. Of these, 3 happened in central Japan, while the remaining 7 originated off the south-eastern coast of the Japanese islands, each being accompanied by great tidal waves.

A consequence of the difference in the seismic activities of the two sides of the Japan arc is that there were on the Pacific coast, 23 great tidal disturbances of seismic origin, while on the Japan Sea coast there were only 5 small cases of such disturbances.

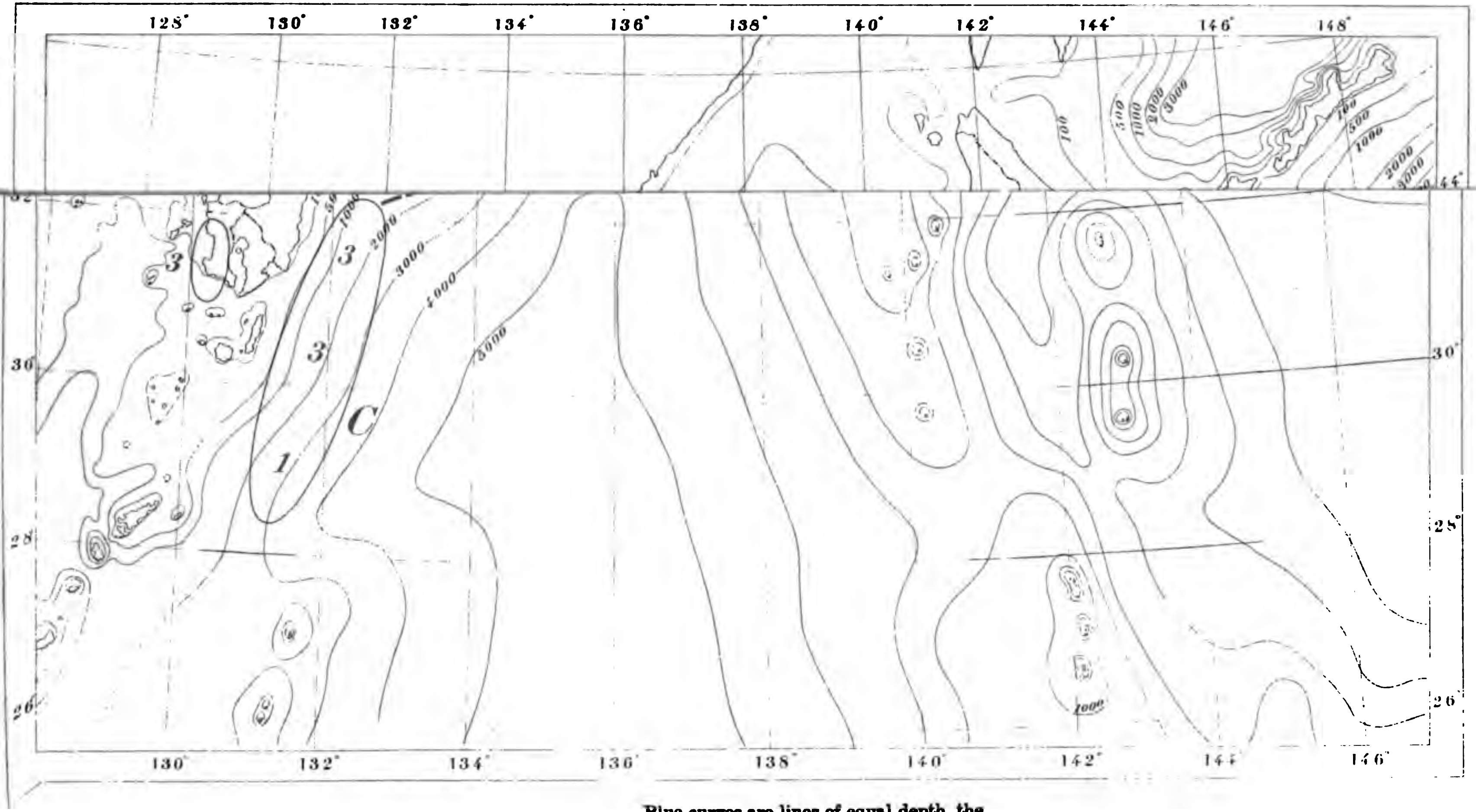
II. RECENT STRONG JAPAN EARTHQUAKES.

8. ***Distribution of the Origins of Strong Japan Earthquakes in Recent Years.*** The systematic earthquake observation in Japan was commenced in 1885, and there were, during the next 21 years, 257 earthquakes which originated in or around Japan, and some of which were destructive or semi-destructive, the rest being strong or moderate shocks, each with a land area of disturbance* greater than about 4,000 square *ri*, or 25,000 square miles. The origins of these 257 earthquakes were distributed among the following 23 groups.

* The *area of disturbance* signifies the area within which the earthquake motion was *sensible*.

Fig. 8. **Distribution of Strong Earthquakes in and about Japan.**

(1885–1905.)

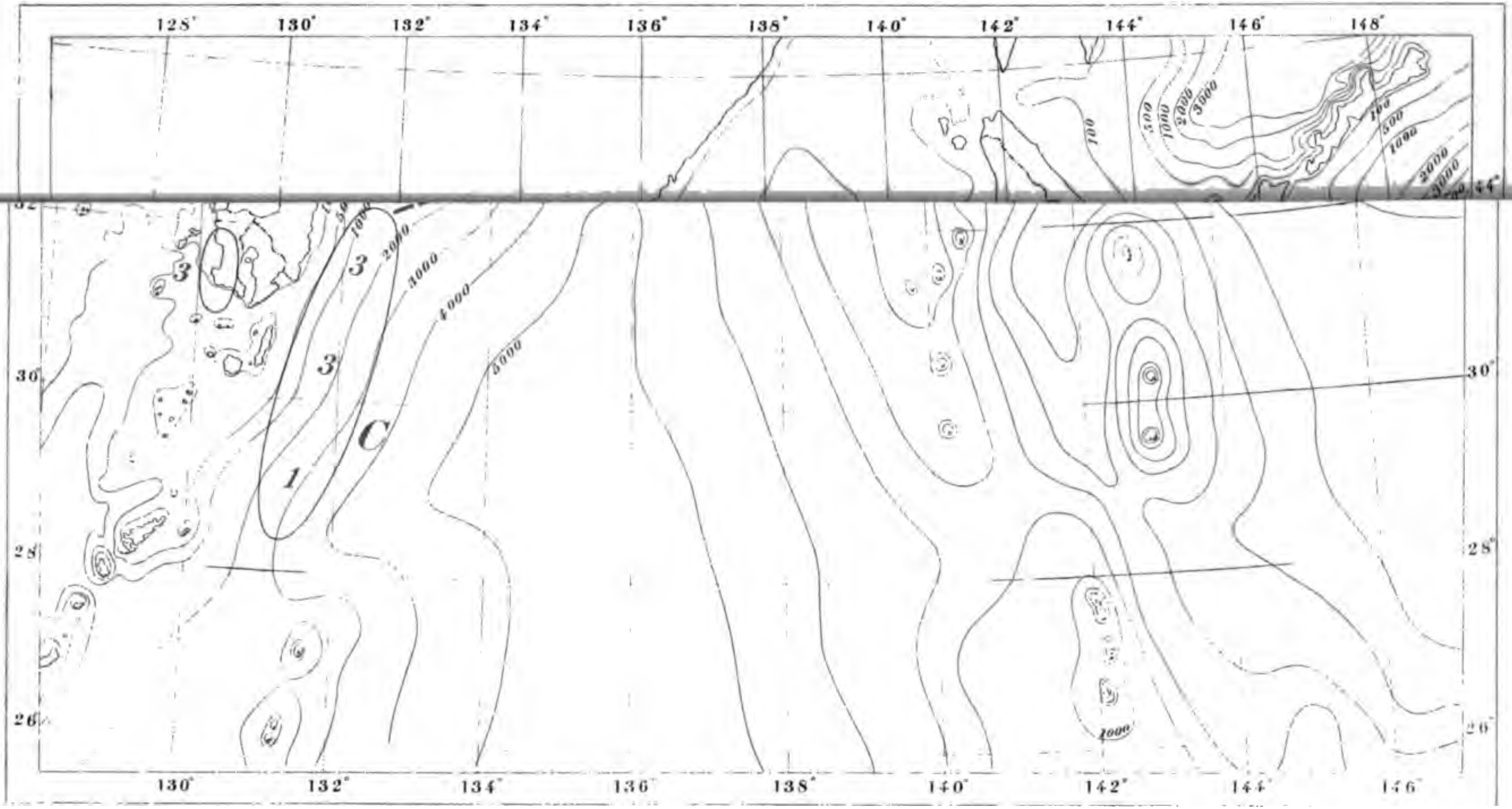


Boundary of provinces.

Blue curves are lines of equal depth, the figures giving the depth in metres.

Figures in red give the numbers of strong earthquakes which originated in the different parts.

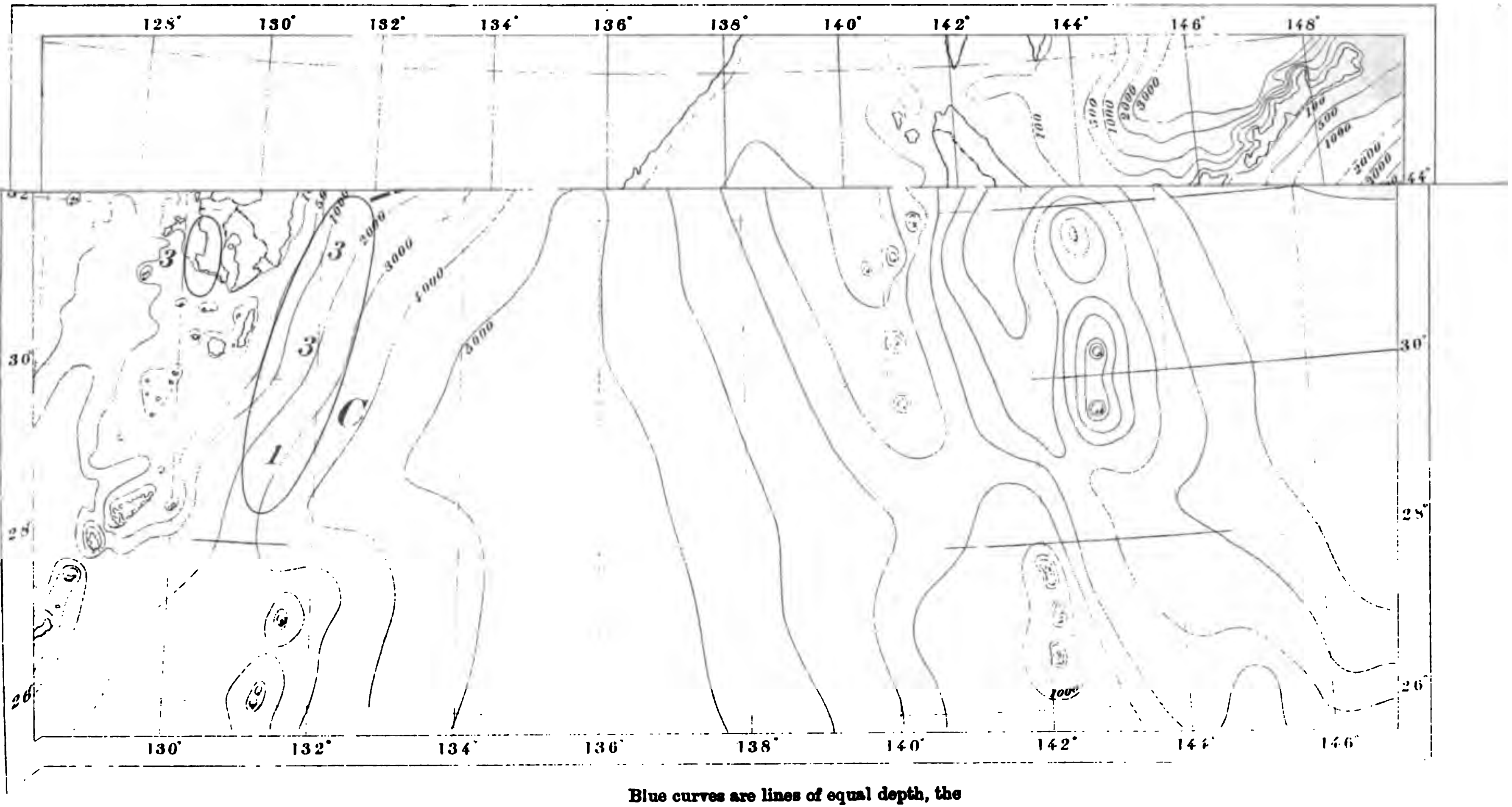
Fig. 8. Distribution of Strong Earthquakes in and about Japan.
(1885–1905.)



Boundary of provinces.

Blue curves are lines of equal depth, the figures giving the depth in metres.

Fig. 8. Distribution of Strong Earthquakes in and about Japan.
(1885–1905.)

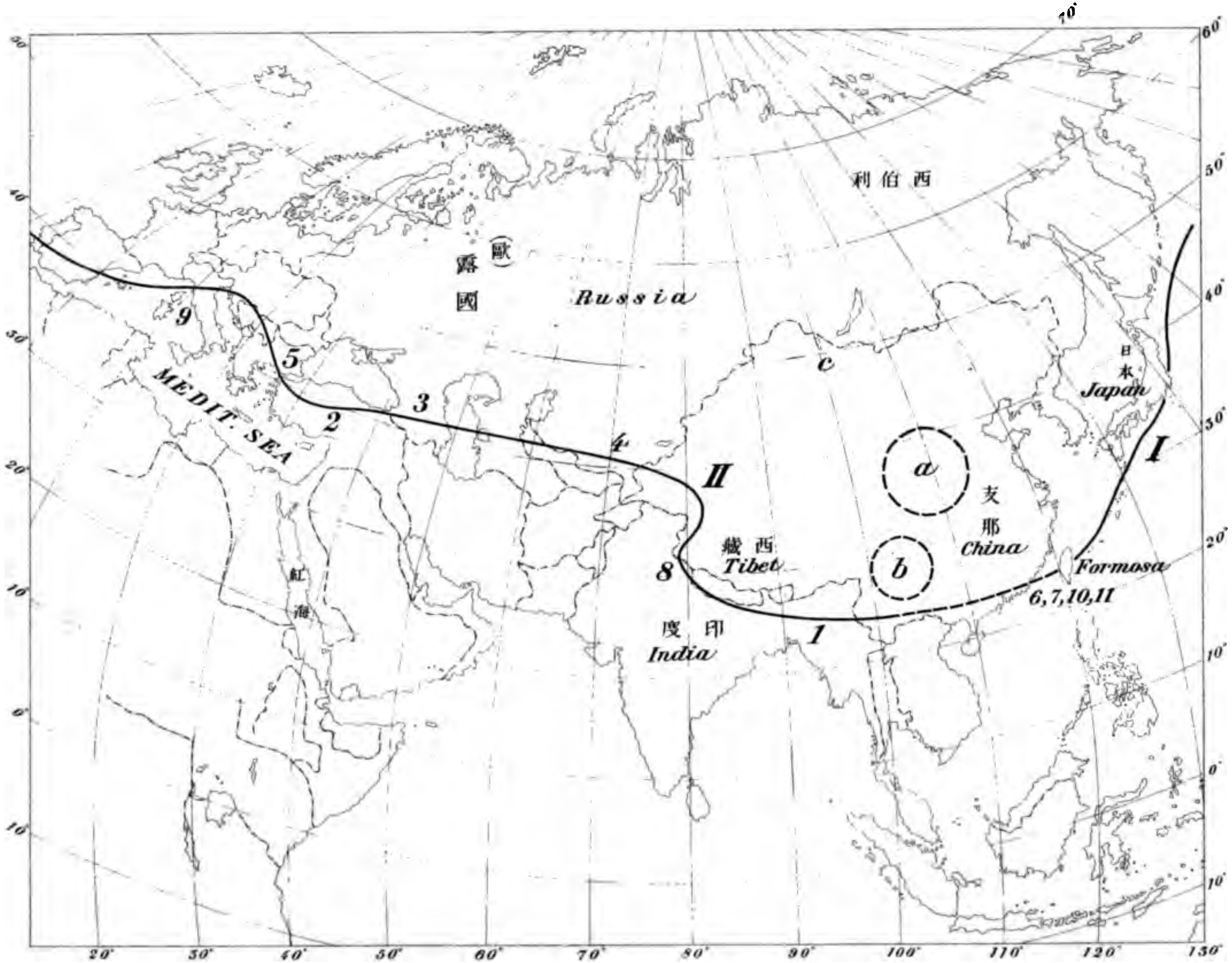


Boundary of provinces.

Blue curves are lines of equal depth, the figures giving the depth in metres.

Figures in red give the numbers of strong earthquakes which originated in the different parts.

Fig. 9. Map Showing Recent Seismic Activity along the Mediterranean and Himalayas Zone.



A. *Off the SE coast of Hokkaido and the E coast of the Main Island.* The 138 earthquakes belonging to this group may be subdivided as follows:—

i.	Off the coasts of Nemuro and Kushiro	25
ii.	Between Hidaka and Mutsu	2
iii.	Off the coasts of Mutsu and Rikuchu	31
iv.	„ „ Rikuzen	28
v.	„ „ Iwaki	19
vi.	„ „ Hitachi	14
vii.	„ eastern coast of the Kazusa-Awa Peninsula	11
viii.	„ coast of Izu	8

B. *Off the E coast of Kii* 1

C. „ *SE coast of Kyushu:*—

i.	In the S part of the Hyuga Nada	3
ii.	„ Vicinity of Yaku and Tane Islands	3
iii.	To the E of Ōshima	1

D. *Off the W coast of Kii* 1

E. „ *Cape of Muroto (Tosa)* 1

F. *Akita and Shōnai District:*—

i.	Off the coast of Akita	1
ii.	Vicinity of Sakata	1

G. *Vicinity of Noto:*—

i.	Off the coast of Toyama (Etchu)	1
ii.	„ W coast of the Peninsula	3

H. *Hoki and Izumo:*—

i.	Off the coast of Hoki	1
ii.	„ „ „ Izumo	2

I. *Western part of Rikuchu and Eastern Part of Ugo* 3

J. *Musashi and Shimōsa District:*—

	i.	NE Part of Musashi	5
	ii.	W Part of Shimosa	4
	iii.	W Part of Hitachi	1
	iv.	S Part of Shimotsuke	2
K.	*Tokyo Bay and Sagami-Nada*:—		
	i.	In Tokyo Bay	9
	ii.	„ Sagami-Nada	2
	iii.	„ Uraga Channel	1
L.	*Sagami, Kai and Suruga District*		5
M.	*Echigo, Shinano, and Hida District*:—		
	i.	Central and W Parts of Echigo	5
	ii.	N Part of Shinano	8
	iii.	E and S Parts of Hida	3
N.	*Mino, Owari, and Echizen District*:—		
	i.	Mino	9
	ii.	Mino and Echizen	1
	iii.	Owari and Mikawa	1
	iv.	In Owari Bay	1
O.	*Vicinity of the Lake Biwa*...		1
P.	*Western half of the Inland Sea*...		23
Q.	*W Part of Chikuzen*		2
R.	*Vicinity of Kumamoto*...		3
S.	*In the S Part of Satsuma, and off the W coast of the Peninsula*		3
T.	*Vicinity of the Ishigaki Island (Loo Choo)*		1
U.	,, ,, *Yaeyama* ,, (,,)		1
V.	*Off the E coast of Formosa*		4
W.	*In the SW Part of Formosa*		2

Fig. 8 illustrates the distribution of the earthquake origins as tabulated above ; Fig. 7, which serves as a key map, giving the names of the different provinces. It will be seen that the most active seismic zone at present is ***A***, or that stretching off the eastern coasts of Hokkaido and Main Island, the number of the earthquakes which occurred in these parts of the Pacific Ocean amounting to 138, or more than half of the total number of the shocks relating to whole Japan. The zone, ***a***, marked by a thick dotted line, represents the approximate focus of the great earthquake* of the 4th year of the Hoyei period (Oct. 28, 1707); the two great shocks in the 1st year of the Ansei period (Dec. 23 and 24, 1854) originating respectively at the eastern half (between Kii and Izu) and the western half (between Kii and Kyushu) of this zone. ***A*** is evidently continued to ***a***, which is itself again continued to the zone ***C***, stretching from the southern part of Hyuga Nada to the east of Ōshima.

A, ***a***, and ***C*** together form the principal sub-oceanic earthquake zone of Japan, which runs parallel to the convex side of the latter and may be named *external seismic zone.* In former times ***a*** was most active, but at present ***A*** is very active.

On the Japan Sea side, there are three seismic regions ***F*** (Akita and Shōnai), ***G*** (vicinity of Noto), and ***H*** (Hōki and Izumo), whose activity is far less than that of the *external seismic zone* above mentioned. Of these three regions, the most important is ***F***, which in historical times produced some violent shocks. ***b*** and ***c*** represent respectively the approximate positions of the great Sado and Shōnai earthquake of Dec. 7, 1833, and the Hamada (Iwami) earthquake of March 14, 1872. These two latter regions form, together with ***F***, ***G***, and ***H***, a continuous band along

* This was the greatest among the earthquakes which ever shook Japan.

the concave side of the Japanese islands, and may be termed the *inner seismic zone.*

Among the other earthquake districts, the most active are:— ***M***, which mainly coincides with the valley of the Shinano-*gawa* and extends from the middle part of Echigo to the northern part of Shinano and the eastern part of Hida; ***K***, Tokyo Bay and Sagami-*Nada*; ***N***, Mino, Owari and Echizen District; and ***P***, the western half of the Inland Sea.

The different earthquake districts shown in Fig. 8 may be divided into two systems, namely, the "concentric" and the "radial," as mentioned in §1. To the "concentric" system belong the *external* and *inner seismic* zones; ***M*** (Echigo, Shinano and Hida); ***K*** (Tokyo Bay and Sagami-*Nada*); ***P*** (Inland Sea), etc. Among the "radial" districts, the most conspicuous is ***N***, or the Mino, Owari and Echizen zone.

9. Seismic Activity along the Mediterranean-Himalayan Zone. Fig. 9 indicates the approximate positions of 11 recent destructive earthquakes belonging to the Mediterranean-Himalayan Zone (marked II), provisionally supposed to extend eastwards to Formosa,* as follows:—

1. Assam and Bengal, June 12, 1897.
2. Aidin (Smyrna), Sept. 20, 1899.
3. Schemacha (Caucasus), Feb. 13, 1902.
4. Kashugar (Turkestan), Aug. 22, 1902.
5. Saloniki (Macedonia), April 4, 1904.

6, 7, 10, 11. Formosa, April 24 and Nov. 6, 1904, and March 17 and April 14, 1906.

* See the *Bulletin*, No. 1, p p. 20—24.

8. Kangra Valley (Punjab, India), April 4, 1905.
9. Calabria (Italy), Sept. 8, 1905.

a, *b* and *c* in the figure indicate the existence of seismic centres in China and the Baikal district, the two former being for the present in a quiet condition. Of the 11 earthquakes, Nos. 1, 2, 4, 5, 8 and 9 were very great disturbances and happened at *different* places along the zone in question.

10. *Relation of Japan Arc to Mediterranean-Himalayan and American Zones.* The most active, or external, seismic zone of Japan (I, Fig. 8) forms a connecting link between the Mediterranean-Himalayan zone and the great American zone, which latter stretches along or off the Pacific coast from Chile on the south to Alaska on the north; ‡ the Aleutian Island earthquake of Aug. 17, 1906, having finally brought the manifestation of the great seismic activity to within 2000^{km} of the north Japan.

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‡ See this Number, p. 100.

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Note on the Direction and Magnitude of the Vibrations in the Different Phases of the Earthquake Motion.*

By

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1. The present note contains the result of study on the observations at Tokyo concerning the magnitude and direction of seismic movements originating from distant centres. The direction of movements is examined with reference to the path of the wave transit, which is assumed to coincide with the great circle passing through the observing station and epicentre; the calculation being made according to the formula

$$\cos\frac{\Delta}{2} = \sqrt{\frac{\sin\frac{-\varphi+\varphi'+\delta}{2}\cos\frac{\varphi+\varphi'-\delta}{2}}{\sin\delta\cos\varphi}}$$

where Δ represents the angle between the great circle and the meridian of the observing station, δ the angular epicentral distance at the latter, and φ and φ' the latitudes of the station and the epicentre respectively.† The direction of the seismic motion has been obtained by composing the two horizontal movements of a few well-defined vibrations at the beginning of the different phases in the seismograms, which were given by Omori H. P. Seismographs registering EW and NS motions.

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* Abstract of a paper read before the meeting of the Imp. Earthq. Inv. Comm. on Dec. 5, 1906, with addition of the discussion of earthquakes Nos. 4 and 9.

† The formula for the calculation of δ is $\cos\delta = \sin\varphi\sin\varphi' + \cos\varphi\cos\varphi'\cos(\lambda-\lambda')$, where λ and λ' represent the longitudes of the observing station and the epicentre respectively.

2. The earthquakes taken into consideration are as follows:—

TABLE I.

Group.	No.	Date.	Epicentre:	λ'	φ'	δ	Δ
I	1	Sept. 29, 1899	Ceram.	129°E	6°S	42° 54'.6	S 15°.8 W
	2	July 29, 1900	New Hebrides.	170°E	17°S	59° 58'.6	S 33°.8 E
	3	June 1, 1906	N. Australia.	139°E	13°S	48° 42'.4	S 1°.1 W
	4	Nov. 19, 1906	W. Australia.	104°50'E	21°27'S	66° 1'.8	S 35°.7 W
II	5	Aug. 22, 1902	Turkestan.	75°E	39°.5N	50° 20'.1	N 65°.1 W
	6	April 4, 1905	India.	77°E	31°.8N	51° 26'.4	N 75°.1 W
III	7	Oct. 9, 1900	Alasca.	140°W	60°N	54° 57'.2	N 37°.0 E
	8	April 18, 1906	San Francisco.	123°W	38°.3N	73° 29'.3	N 54°.2 E
	9	Jan. 31, 1906	Columbia.	79°W	5°N	125° 26'.7	N 50.°0 E

Of these, the first four originated in Javan district, the next two in the Himalayan district, and the last three in the Pacific side of America. Thus the earthquakes in Groups I, II and III were propagated to Tokyo nearly from south, west, and north-east, respectively.

3. The positions of the epicentres given in the table were obtained as centres of the most disturbed areas, except for the suboceanic earthquakes Nos. 2–4, whose origins were determined by means of the following observations concerning the time of commencement.*

No. 2:—7^h 8.7^m at Tokyo, 7^h 9.7^m at Batavia, 7^h 11.7^m at Calcutta, 7^h 12.0^m at Victoria, 7^h 15.2^m at Mauritius, 7^h 17.8^m at Cape of Good Hope.

No. 3:—4^h 38.2^m at Tokyo (dur. of p. t.$=8^m$ 25^s), 4^h 38.2^m at

* Time is given in Greenwich mean time.

Osaka (dur. of p. t.$=8^m$ 25^s), 4^h 35.8^m at Perth, 4^h 37.1^m at Batavia, 4^h 41.9^m at Bombay, 4^h 39.8^m at Calcutta.

No. 4:—7^h 28.9^m at Tokyo (dur. of p. t.$=16^m$ 13^s), 7^h 20.5^m at Perth.

The most important datum for the determination of the epicentre in No. 4 is the observation of the sea-quake on board the steamer Omrah at a point *long.* 104°50′E, *lat.* 21°27′S.

4. That the different phases of seismic movements have different directions may probably be best understood from the diagram of the earthquake No. 3. (see Pl. XXX.) In the seismogram, not only the commencement of the 1st prel. tremor (I), but also that of the 2nd one (II) and its successive waves (a-d) are larger in the NS than in the EW component, while this relation is quite contrary in the 1st princ. portion (III-D). It will also be seen that the 3rd phase of the princ. portion (V-γ) is enlarged in the NS component only. I have hardly any reason to assume such peculiarities as errors due to the instruments which are most reliable ones in our Institute, the pendulums of EW and NS components having 61.5 and 48.5 sec. as the periods of free vibration, and 15 and 20 times as the magnifications of their writing indices respectively. The same instruments registered both components in Nos. 4, 6 and 9, and NS component in No. 8. The other component in the last named earthquake is taken from the illustration given by Prof. Omori in the Publ. of the Imp. Earthq. Inv. Comm., No. 21, Appendix II. With respect to the diagrams of the four other earthquakes, the EW component in Nos. 1 and 5 was recorded by the instrument A, that in Nos. 2 and 7 by D and C respectively, while the NS component in Nos.

TABLE

Earthquake No.	Component.	1st preliminary tremor.						2nd preliminary tremor.							
		I-a' a'-b' b'-c' aver. mm.				Resultant		II-a a-b b-c c-d d-e aver. mm.						Resultant	
		I-a'	a'-b'	b'-c'	aver.	dir.	amp.	II-a	a-b	b-c	c-d	d-e	aver.	dir.	amp.
1	E-W W-E	Began gradually.				—	—	·15	·10	·10	·20		·14	S27°·4W	·30
	N-S S-N	Bagan abruptly.						·24	·17	·17	·49		·27		
2	E-W W-E	Began gradually.				—	—	·65	1·54	1·07	·48		·95	S41°·8E	1·42
	N-S S-N	Began very abruptly.						·75	1·20	1·50	·80		1·06		
3	E-W W-E	Began gradually.				—	—	·07	·07	·07	·07		·07	Due S	·67
	N-S S-N	Began abruptly.						·24	·75	1·05	·65		·67		
4	E-W W-E	Began gradually.				—	—	·17	·33	·33	·20		·26	S33°·7W	·47
	N-S S-N	Began gradually.						·20	·40	·56	·40		·39		
5	E-W W-E	Began gradually.				—	—	·40	·55				·48	N42°·0W	·72
	N-S S-N	Began gradually.						·40	·65				·53		
6	E-W W-E	·39	·54	·37	·43	N64°W	.48	·78	2·40	4·73	5·78	5·12	3·76	N53°·6W	4·68
	N-S S-N	·16	·25	·23	·21			·53	2·30	3·90	3·78	3·40	2·78		
7	E-W W-E	Began gradually.				—	—	·78	·78	·25	·78		·65	N36°·8E	1·08
	N-S S-N	Beginning large.													
8	E-W W-E	Began gradually.				—	—	1·31	3·33	3·33	2·32		2·57	N46°·2E	3·57
	N-S S-N	Began gradually.						1·70	3·05	2·97	2·20		2·48		
9	E-W W-E	Began very gradually.				—	—	·67	2·60	4·66			2·64	N59°·9E	3·05
	N-S S-N	Began very gradually.						·65	1·75	2·16			1·53		

II.

1st principal portion.								3rd principal portion.						
III-A	A-B	B-C	C-D	D-E	aver. mm.	Resultant dir.	Resultant amp.	V-α	α-β	β-γ	γ-δ	aver. mm.	Resultant dir.	Resultant amp.
3·2	5·4	5·0	2·7		4·1	N79°·4W	4·2							
·85	·68	·73	·79		·77									
1·78	3·3	2·9			2·6	N77·0°·E	2·7	·18	·71	·65	·36	·48	S25°·5E	1·12
·45	·84	·50			·60									
·53	1·30	2·73	1·33		1·60	N99°·2W	1·62	·28	·73	1·30		·77	N11°·2E	4·0
·08	·20	·35	·39		·26			3·1	4·9	3·7		3·9		
·22	·37	·37			·32	N64°·8W	·35	·13	·23	·15	·10	·15	S15°·0W	·58
·11	·13	·20			·15			·38	·51	·62	·73	·56		
·50	·60	·90	1·15	·93	·83	N19°·3E	2·44	8·2	10·2	8·05	8·5	8·74	N58°·5W	10·2
1·63	2·17	2·53	2·58	2·60	2·30			5·75	6·4	4·7	4·6	5·36		
1·25	1·00	·73	1·78		1·19	N17°·7E	3·93							
2·61	3·15	3·75	5·45		3·74									
1·70	2·20	1·66			1·35	N63°·1W	2·38							
·62	·98	1·22			·94									
·40	·33	·33	·36	·33	·35	N27°·5W	·76							
·70	·33	·20	·58	1·55	·67									
1·73	1·13				1·43	N35°·1W	2·48							
1·70	2·35				2·03									

1 and 7 was given by B, and in Nos. 2 and 5 by one whose magnification was 10 times, and whose period of free vibration was 30 sec.*

5. Table II shows the range of motion (double amplitudes) of the different phases together with the resultant directions and magnitudes. The numbers in the row E-W show the ranges of motion from *east to west*, and those in W-E the magnitudes in the opposite direction.

6. Table III gives the relation between the directions of the 2nd preliminary tremor (II), the 1st (III) and 3rd principal portions (V) and that of propagation. The deviation of directions with positive or negative sign means the angle through which the direction of movement deviated from that of the path in the counterclockwise or clockwise sense. As it will be seen from the average values, the directions of the 2nd preliminary tremor and the 3rd principal portion are almost coincident with the path, while that of the 1st principal portion is nearly normal to the latter.

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* For the details of the instruments, the reader is referred to Prof. Omori: Publ. of the Imp. Earthq. Inv. Comm. in Foreign Languages, No. 21.

TABLE III.

No.	δ		Direction.				Deviation of direction.			Range of motion.				
			Δ	II	III	V	II	III	V	II	III	V	III/II	V/II
										mm.	mm.	mm		
1	42°	54′·6	S15°·6W	S27°·4W	N79°·4W	—	−11°·6	+95°·2	—	·30	4·2	—	14·0	—
2	59°	58′·6	S33°·8E	S41°·8E	N77°·0E	S25°·5E	+ 8°·0	+69°·2	− 8°·3	1·42	2·7	1·12	1·90	·79
3	48°	42′·4	S 1°·1W	S-N	N99°·2W	N11°·2E	+ 1°·1	+100°·3	−10°·1	·67	1·62	4·0	2·42	6·0
4	66°	1′·8	S35°·7W	S33°·7W	N64°·8W	S15°·0W	− 2°·0	+100°·5	−20°·7	·47	·35	·58	·74	1·23
5	50°	20′·1	N65°·1W	N42°·0W	N19°·8E	N58°·5W	−23°·1	+95°·1	− 6°·6	·72	2·44	10·2	3·40	14·2
6	51°	26′·4	N75°·1W	N53°·6W	N17°·7E	—	−21°·5	+87°·2	—	4·68	3·93	—	·84	—
7	54°	57′·2	N37° 0E	N36°·8E	N63°·1W	—	+ 0°·2	+100°·1	—	1·08	2·38	—	2·21	—
8	73°	39′·3	N54°·2E	N46°·2E	N27°·5W	—	+ 8°·0	+81°·7	—	3·57	·76	—	·21	—
9	125°	26′·7	N50°·0E	N59°·9E	N35°·1W	—	− 9°·9	+85°·1	—	3·05	2·48	—	·81	—
Average.							− 5°·6	+90°·5	−11°.4	1·77	2·32	3·98	2·95	5.56

7. The result contained in the foregoing § § may be summarized as follows:—

(*a*) The direction of the 1st prel. tremor, when it is distinct, tends to coincide with that of the path.

(*b*) The 2nd prel. tremor, whose direction coincides with the path, may possibly consist of longitudinal waves.

(*c*) The 1st princ. portion, whose direction is normal to the path, may possibly consist of transverse waves.

(*d*) The paths of the two last mentioned phases are probably common, as there are rocks of older geological formation giving as much transit velocities for the seismic waves of longitudinal and transverse types as the 2nd prel. tremor and the 1st princ. portion.

(*e*) Of the magnitude of the different phases, the 3rd princ. portion is the largest, but no definite relation could be found for the two other phases. In fact, the 2nd prel. tremor was larger than the 1st princ. portion in the earthquakes nos. 4, 6, 8 and 9 which had more distant origins, while this relation was quite contrary in the case of the nearer earthquakes.

(*f*) Similarity of the seismic motion originating at neighboring centres* is probably due to the existence of definite directions for the different phases and similarity of the path. With respect to the latter statement, the earthquakes of Group I, which were propagated along suboceanic paths, had the principal portion slightly developed in magnitude and duration when compared to the preliminary tremor, while those of Group II, mostly propagated along the free surface layer had well developed principal portion. This property, however, requires further investigation.

Jan. 1907. Seismological Institute, Tokyo.

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* See Prof. Omori: Publ. of the Imp. Earthq. Inv. Comm. No. 21.

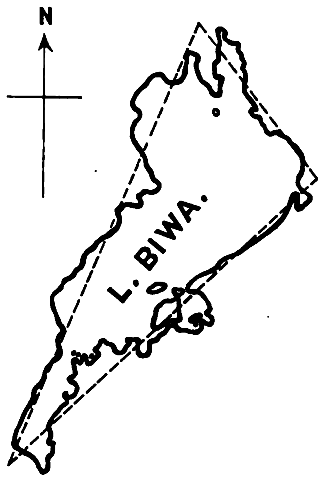


Fig. 2.
Showing the approximate form of the Lake Biwa.

45° to the central line or arc of the Japanese islands. As shown by the dotted line in Fig. 2, the Lake of Biwa is roughly triangular in form, and it is the object of the present note to see, if any, the relation among the earthquake zones in Central Japan with reference to the lake.

2. *Zones of Destructive Earthquakes in Central Japan.* Great destructive earthquakes in Central Japan, whose origins can be more or less accurately ascertained, are the 5 following:—

(i)	Eqke of the 1st year of	Keichō	:	Sept. 4, 1596.*
(ii)	,, ,, 2nd ,,	Kwanbun	:	June 16, 1662.
(iii)	,, ,, 1st ,,	Tempō	:	Aug. 19, 1830.
(iv)	,, ,, 1st ,,	Ansei	:	July 9, 1854.
(v)	Mino-Owari	Eqke	:	Oct. 28, 1891.

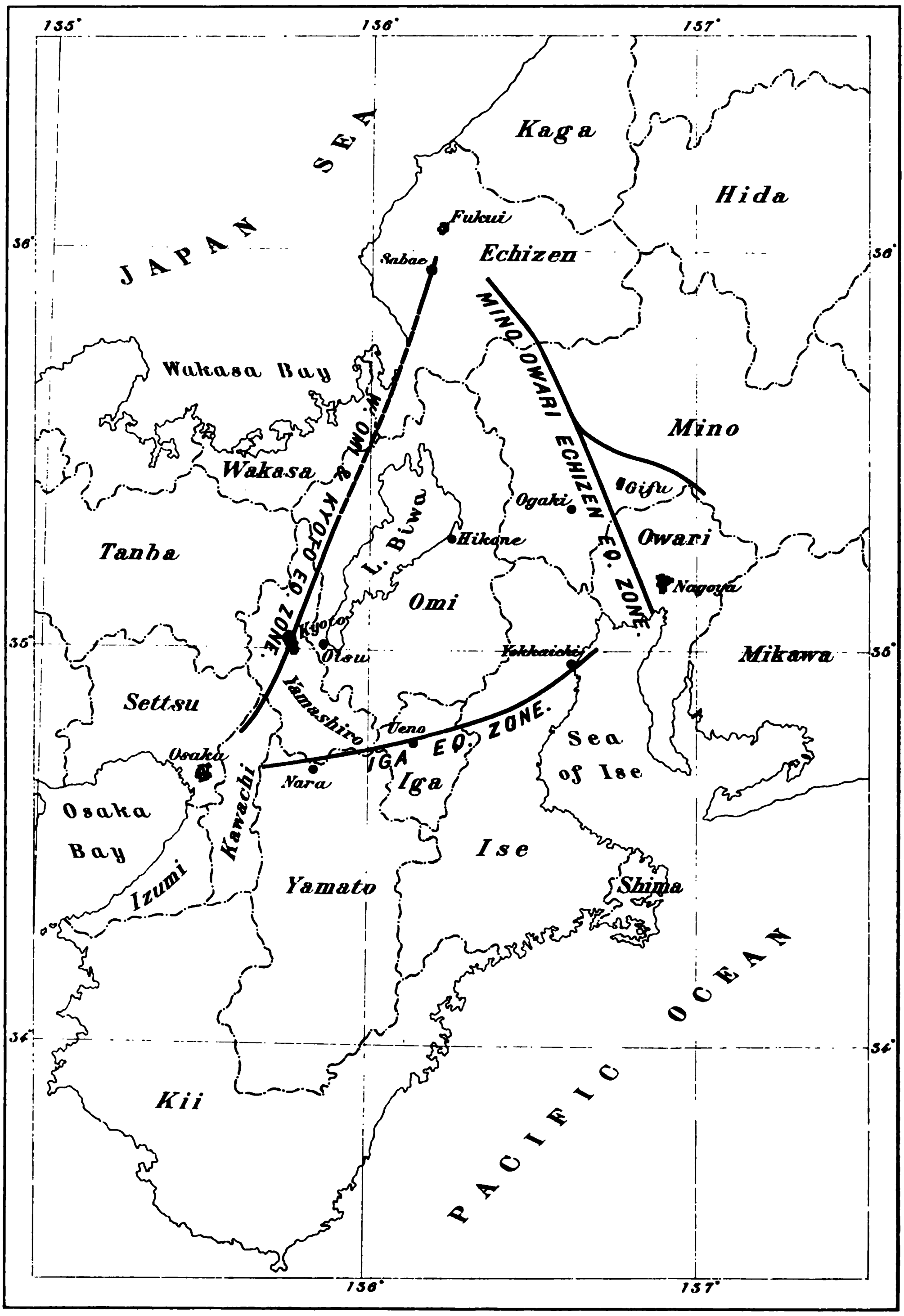
The Keichō earthquake (No. i), which was very violent and became famous from the destruction of the great Fushimi Castle erected by Taikō (Toyotomi Hideyoshi), had its origin in the district extending from the southern part of Kyōto to the towns of Fushimi and Yodo. On the other hand, the Kwanbun earthquake (No. ii), which was very violent and extensive in area, originated about 40 km to the NNE of the first earthquake, namely, to the west of Mount Hira, at the boundary of the northern part of

* Prior to this date there were several destructive earthquake in Kyoto and the vicinity, the earliest great shock having occurred in 827. It is, however, impossible to locate exactly their origins.

Fig. 3. Earthquake Zones in Central Japan.

——·——·—— Boundary of provinces.

W. Omi and Kyoto EQ. Zone .... (*A*).
Iga EQ. Zone .... (*B*).
Mino Owari Echizen EQ. Zone .... (*C*).



the province of Yamashiro and the western part of the province of Ōmi. The Tempō earthquake (No. iii), which was smaller than the Keichō and Kwanbun shocks, originated between the centres of the two latter, being strongest in the northern part of Kyōto and the adjacent region to the north. Thus, it will be observed that the three earthquakes above mentioned all originated along a line which extends from the western part of Ōmi to the vicinity of Ōsaka, in the direction of N20°E and S20°W. This earthquake zone, which may be called ***A***-Zone, (Fig. 3), passes on the north through the city of Fukui (province of Echizen); it being specially interesting that the severe earthquake of March 22, 1900, which was felt strongly in the vicinity of the town of Sabaé (Echizen), originated just on the northern prolongation of the zone under consideration. It will be seen that the occurrence of the different earthquakes along ***A*** was in accordance with the principle explained in the next Article.

The Ansei earthquake* (No. iv) was a very extensive shock and was most violent about the city of Uéno (province of Iga), the epifocus, ***B***-Zone (Fig. 3), being a zone about 100 km in length, which extends in a mean direction of S70°W—N70°E from the vicinity of the city of Nara (province of Yamato) to that of the city of Yokkaichi (province of Ise). The western end of this zone also points to the city of Ōsaka, on the head of the Ōsaka Bay.

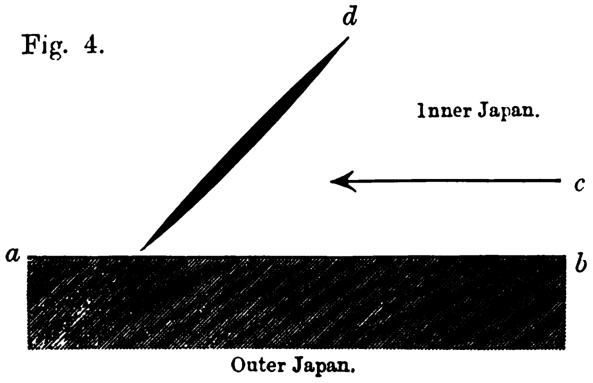
Finally, the great Mino-Owari earthquake was caused by tectonic disturbances which produced faults extending from the central part of the province of Echizen to the south-eastern part of the

* This is different from the two great earthquakes, also in the 1st year of Ansei, which originated off the south-western coast of Japan, respectively on the 23rd and 24th, Dec. 1854.

province of Mino, the vertical and horizontal convulsions of the ground being most markedly manifested in the famous Néo-Valley of the latter province. There was very probably an underground line of disturbance which formed a direct southern prolongation of the Néo-Valley fault, reaching down to the head of the Bay of Ise. On the whole, the direction of the epifocus, ***C***-Zone, (Fig. 3), of the Mino-Owari earthquake was N 20° W —S 20° E.

The three earthquake zones, ***A***, ***B***, and ***C***, form approximately a right-angled triangle, whose hypothenuse is ***A***, and whose right angle is formed by ***B*** and ***C***, these two latter sides being inclined to the former at an angle of 45° or 50.° The great destructive earthquakes in the central part of Japan seem always to originate at some parts of the sides of this seismic triangle, which is roughly similar to, and similarly situated as, the triangle formed by the Lake Biwa. It thus appears probable that the latter was formed as the result of the existence of some forces in the earth's crust in this part of Japan. The zones ***B*** and ***C*** may be regarded as being respectively *parallel* and *normal* to the general arc or central line of the Japanese islands.

Fig. 4.



The formation of the zone ***A*** may be explained by the application of the theory of the *secondary*, or *shear*, cracks accompanying the fault produced in the epifocal zone of a destructive

earthquake.* Thus let *ab* (Fig. 4) represent the boundary between the convex, or outer, side and the concave, or inner side, of the Japan arc. If now the latter side be sheared relatively to the former as shown by the arrow *c*, then there ought to be produced some oblique cracks, as *d*, which is inclined to the boundary line, *a b*, at an angle of 45°. *d* corresponds to the seismic zone ***A*** or the depression formed by the Biwa Lake and the Osaka Bay. That some such action of the terrestrial forces as above imagined took place seems probable, since the geological formations on the exterior or convex side of the Japan arc are regular in arrangement, while those on the inner or concave side are very irregular and complicated.

* See the *Bulletin*, No. 1.

Recent Strong Earthquakes in the Shinano-gawa Valley (Central Japan).

By

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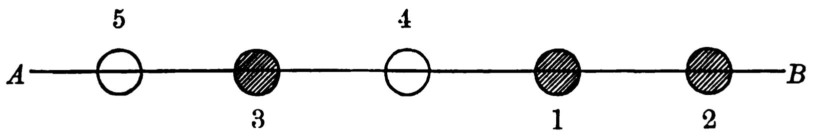
1. ***Introduction.*** Destructive earthquakes, whether great or local, are generally not isolated phenomena, but form groups each of which happen along a seismic zone of greater or less extent; no two violent shocks occurring successively at one and the same place. Thus let A B (Fig. 1) represent a seismic zone; 1, 2,

Fig. 1.



3, 4 and 5 being different earthquake centres. If now the first two earthquakes took place at 1 and 2 respectively and the 3rd one at 3, the next shock may be expected to occur somewhere at 4. Again, after the occurrence of the earthquakes 1...4, the 5th one may be expected to happen towards either end of the zone under consideration, say at 5.

2. ***Strong Earthquakes in the Shinano-gawa Valley.*** The case diagrammatically illustrated in Fig. 1 has exactly been verified by the 5 strong earthquakes, which happened, between the years 1886 and 1899, in the Shinano-gawa valley; the latter

forming one of the active seismic zones in the central part of the Main-Island.* The dates of these 5 earthquakes are as follows:—

No. 1. July 23, 1886 ; 1.00 A.M.
,, 2. July 22, 1887 ; 8.30 P.M.
,, 3. Jan. 7, 1890 ; 3.43 P.M.
,, 4. Jan. 17, 1897 ; 5.36 A.M.
,, 5. Jan. 22, 1899 ; 8.04 A.M.

It may by the way be noted that the first two earthquakes occurred at an almost identical epoch of the year, namely, on 23rd and 22nd of July, while the three remaining ones occurred all in July. This is one of the instances, in which strong or destructive earthquakes belonging to a given seismic zone tend to occur at nearly the same hour in the day, or in the same month of the year. The approximate positions of the epicentres of the 5 earthquakes are indicated in Fig. 2 by the numerals 1, 2, 3, 4, and 5 respectively.

Eqke No. 1 originated at the boundary of the two provinces of Echigo and Shinano, and was strongly felt in the counties of Higashi-Kubiki (Echigo) and Midochi (Shinano), causing a destruction of one house, besides several cases of damage to *dozo* (Japanese ware houses), *ishigaki* (stone retaining walls), etc. Some cracks of the ground were also produced.

Eqke No. 2 originated in the Koshi county, (province of Echigo), where the ground was cracked and water and sand were ejected; some temples being displaced 2 to 6 inches on their foundations, and one person wounded. The shock was also strongly felt in the two counties of Mishima and Minami-Kanbara (Echigo).

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* This is the zone marked M in my paper on the Distribution of Recent Japan Earthquakes. The *Bulletin*, No. 2.

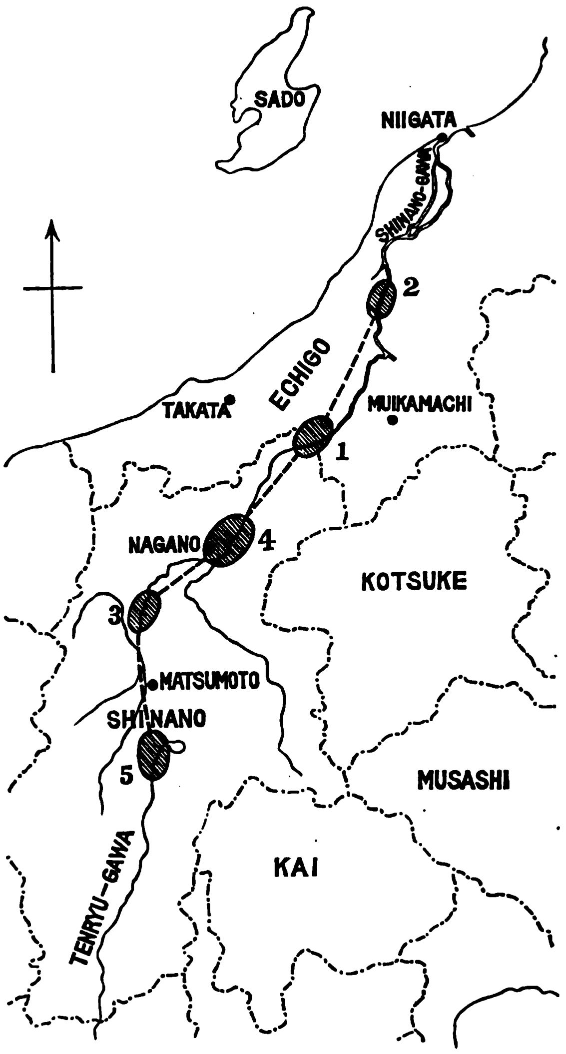

Fig. 2.

Map illustrating the Shinano-gawa Eq. Zone. Small shaded ellipses indicate the approximate positions of the Eq. Origins.

Eqke No. 3 was most severely felt in the counties of Kami-Midochi, Higashi-Chikuma, Kita-Atsumi, and Sarashina (all in the province of Shinano). Houses and *dozos* were damaged, cliffs and roads were cracked, tomb stones were overturned, water and sand were ejected from ground cracks.

Eqke No. 4 was severely felt in an area of about 60 square miles in the two counties of Kami-Takai and Kami-Midochi (in the province of Shinano). The seismic damage was nearly the same as in Eqke No. 3, the epicentre being probably situated on the eastern side of the Shinano-*gawa*.

Eqke No. 5 was strongly felt in the counties of Suwa, Kami Ina, and Higashi-Chikuma (in the province of Shinano), the centre of disturbance being in the vicinity of Lake Suwa. In this case, the motion was not so intense as in the four preceding

shocks, due probably to a greater depth of its origin.

Summary. It will be observed that the 5 earthquakes above described were each a local severe shock, whose damge was limited to cracks of the ground, some injury to buildings, and the like. Further, (2) originated about 33 miles to the NNE of (1), while (3) originated at a greater distance in the opposite direction, at 50 miles to the SW of (1), namely, a little distance to the SE of the town of Ōmachi. Thus it was very likely that the next place to be visited by a strong shock was between (1) and (3). This has been fulfilled by the occurrence of the next earthquake at (4) or the vicinity of the city of Nagano. The famous great earthquake of Zenkōji on May 11, 1844, was of the same character as, but much more violent than, Eqke No. 4.

The occurrence of Eqke No. 5 further southwards was in accordance with the natural order of things to be expected.

3. *Seismic Activity in America, Asia and Europe.* The successive occurrence in recent years of a number of destructive earthquakes along the American and Mediterranean-Himalayan seismic zones* furnish another illustration of the principle explained in § 1, manifested in a grand scale.

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* See the *Bulletins*, Nos. 1 and 2.

Note on the Eruptions of the Unsen-daké in the 4th year of Kansei (1792).

By

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Member of the Imperial Earthquake Investigation Committee.

The eruptions in the 4th year of Kansei (1792) of the Unsen-daké which stands on the peninsula of Shimabara, in the province of Hizen (Kyushu), extended over a period of nearly 4 months. They were preceded, for several weeks, by a number of small shocks, which caused some landslips from mountain slopes; the first eruption having taken place on Feb. 12, 1792, at midnight, near the top of the Fuken-san (1478m above the sea level), one of the highest peaks of the mountain. Subsequently there were several eruptions from different neighbouring places, attended by numerous detonations and earthquake shocks. Of the latter, those on April 21st and 22nd (March 1st and 2nd, Lunar Calendar) were the strongest, causing in the town of Shimabara some damage to buildings and cracks of the ground about 1 inch in width. The final catastrophe occurred at about 6 o'clock in the evening of May 21st, (April 1st, Lunar Calendar), when two violent earthquake shocks took place, and the entire southern slope of the Mae-yama (876m above sea level), which is opposite the town of Shimabara, slipped down, producing an immense avalanch of rocks and earth. The latter quickly descended into the sea of Ariaké, which separates the Peninsula from the province of Higo,

causing a considerable change in the topography of the harbour. Amongst others, three small islands were wiped out of existence, and several dozen others newly created. Simultaneously with the landslip, great sea waves were formed, which rolled in along the shore and attained at some places a height of 20 to 30 feet, causing devastations among 17 villages along the eastern coast of the Peninsula for a distance of 77 km. The number of the casualties on this side of the Ariaké Sea amounted to 9,745 persons killed and 707 persons wounded, besides 496 cattle and horses. The sea waves produced also a considerable amount of damage on the eastern shores of the Ariaké Sea, namely, in the counties of Akita, Udo, and Tamana, of the province of Higo, where the total number of persons killed amounted to 5,100. Along the coasts of the Amakusa Islands, 343 people were drowned. Earthquake shocks continued to happen for the next two months.

The local earthquakes which accompanied or preceded the eruptions of the Unsen-daké were not very destructive, but much severer than is usually the case with volcanic *explosions*. In these latter cases, as with the recent outbursts of Japanese volcanoes, namely, Bandai-san (1889), Azuma-san (1893), Adataro-san (1900), and Tori-shima (1902), the phenomenon is purely that of a steam explosion, and the volcanic force is mainly spent in blowing and projecting mountain masses, only a small amount of the energy being transformed into earthquake vibrations On the other hand, in eruptions like those of the Unsen-daké, which were attended by no gigantic explosion, the subterranean volcanic energy would be in a great measure spent in causing mechanical vibrations, resulting in comparatively severe earthquake shocks.

The cause of the great Shimabara sea waves seems to have been the disturbances of the waters by the enormous quantity of

rock and earth masses thrown into latter. Thus the volume of the *debris* was roughly 0.55 cubic km, or equivalent to an area of 550 square km, with a thickness of 1 metre. Such an area is nearly equal to that of the Ariaké Sea, which is an inland body of water included between the two provinces of Hizen and Higo, and the volume of the *debris* thrown suddenly into the sea seems to be sufficient to produce an initial displacement of the surrounding water masses, the disturbances thereby created being propagated to the different parts of the shores, where tidal waves were formed. The great landslips from the Mae-yama was evidently the effect of the local but violent earthquake shocks.

Instances exactly similar to the Unsen-daké eruptions are not rare. Thus, the eruption in 1868 of Mauna Loa, in the Island of Hawaii, began on March 27 of that year. On April 2, there took place a severe earthquake shock, which did some damage to buildings in the vicinity, causing at the same time, a landslip of an enormous quantity of soft clay from the head of a ravine called Kapapala at the south-eastern flank of the mountain. This produced a mud stream, half a mile in width and about 30 ft. in depth at the centre, which descended into the sea in the interval of only a few minutes, over a distance of 3 miles. The result was the immediate formation of large sea waves, which rolled in along the shore of Kau district, attaining a height of 40 to 50 feet.

The sea waves attending the great eruptions of Krakatoa in 1883 were also probably caused in a measure by the ejection of the rock masses into the surrounding sea waters.

Seismograms Showing no Preliminary Tremor.

By

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1. *Introduction.* The examination of the horizontal pendulum diagrams of the Japan earthquake of Jan. 21, 1906, which originated off the south-eastern coast of the Main Island, has accidentally revealed that some earthquake motion indicates no preliminary tremor when observed at places situated in certain directions relative to the seismic origin; the earthquake of Feb. 6, 1907, also indicating the same fact. Studies in this connection may throw much light on the nature of the vibrations composing the initial part of the *macro-seismic* earthquake motion; the present note giving a short account of the observations of the earthquake of Jan. 21, 1906. I have here to express my thanks to Mr. N. Shimono, Director of the Ōsaka Meteorological Observatory, for his valuable suggestions and assistance given me in connection with the investigation of the earthquake in question.

2. *Isoseismals.* (Fig. 1.) The earthquake was felt as a slight or moderate shock over a considerable area, which extended from the south-eastern portion of Hokkaido on the north-east to the strait between the islands of Shikoku and Kyushu on the south-west; the boundary of this area, or the isoseismal *I*, being symmetrical with respect to a line, which is normal to the Japan arc and connects the cape Inuboé (province of Shimosa) with the

southern end of the Sado island. The isoseismal line *II* includes the area within which the shock was *strongly* felt.

The earthquake was recorded by Omori Horizontal Pendulums at the different stations in Japan and also at the Meteorological Observatory of Zikawei, near Shanghai.

3. *Position of the Origin.* The approximate position of the earthquake origin may be inferred from the seismograms obtained at Tokyo, Mount Tsukuba, Mito, and Miyako (province of Rikuchu), where the preliminary tremor was clearly observed, as follows.

Place.	Duration of 1st Prel. Tremor $=y$.	Epicentral Distance (*Calculated*) $=x$
Tōkyo	43 sec.	350 km
Mt. Tsukuba	43	350
Mito	47	380
Miyako	78	610

The epicentral distances given in the above table have been calculated by the formula*

$$x^{km} = 7.27\ y^{sec.} + 38^{km}.$$

The 4 circles drawn about Tokyo, Mt. Tsukuba, Mito, and Miyako, as centres with the corresponding calculated values of the epicentral distances for the radii, meet as shown in Fig. 1 at points which are close to one another. The approximate position of the earthquake origin thus determined is

$$\varphi = 34° \ 23'N, \qquad \lambda = 143° \ 26'E\ ;$$

* The *Publications*, No. 13.

the actual arcual distances from the epicentre, the time* ($=t_1$) of earthquake occurrence, and the duration ($=y$) of the preliminary tremor, for the different stations being as follows.†

Place.	Epicentral Distance $=x$.	Time of occurrence $=t_1$	Duration of Prel. Tremor $=y$
Tōkyo	3° 17′=365 *km*	$10^h\ 50^m\ 31^s$ P.M.	43 sec.
Mt. Tsukuba ...	3 18 =367	10 51 15	43
Mito	3 09 =350	10 50 33	47
Mizusawa	5 06 =567	10 51 45	67
Miyako	5 23 =598	10 52 44 (?)	78
Ishinomaki	4 23 =487	———	
Osaka	6 32 =726	10 50 28	0
Kyōto	6 21 =705	———	0
Kōbe	6 49 =758	10 50 30	0
Tadotsu	8 00 =889	10 50 23	0
Shanghai	18 57 =2106	10 52 15	141
Taihoku	21 10 =2352	10 53 20	180
Taichū...	22 15 =2472	10 52 12 (?)	177
Hōkoto	23 27 =2606	10 51 15 (?)	202
Manila...	28 20 =3148	10 54 23	281 (?)

4. *Character of the Seismograms.* The seismograms at the different stations are shown in Figs. 2—15, as follows.

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* The times are given in the 1st Normal Japan Time, or that of longitude 135° E.

† All the observation made with Omori Hor. Pendulum, except that at Manila which was made with Vicentini Seismograph.

No. of Fig.	Station.	Component.	Multiplication.	Pendulum Period.
2	Ōsaka	EW	20	27 sec.
3	„ (slow time rate)...	„	10	30
4	Kyōto	„	20	30
5	Kōbe	NS	20	25
6	Ishinomaki	EW	11	25
7	Tōkyo (Hitotsubashi)	„	10	24
8	„ (Hongō)	„	120	26.5
9	„ „	NS	20	48.5
10	„ „	EW	15	61.5
11	„ „	Vertical	30	2.0
12	„ „	„	12	4.5
13	Taihoku (Formosa) ...	EW	10	23
14	Mito	„	20	28.8
15	Miyako	„	120	18

From Figs. 2—15, it will be observed that the seismograms obtained at Tōkyo, Mito, Miyako, Ishinomaki, and Taihoku,* indicates the preliminary tremor in the usual way, while those obtained at Ōsaka (EW) and Kyōto (EW) has no preliminary tremor at all. In the Kōbe seismogram (NS), the motion was quite large at the very commencement as was the case with the two last-mentioned places; there being, however, an ill-defined indication of the preliminary tremor.

I give next a short description of the seismograms obtained at the three stations of Ōsaka, Kōbe, and Taihoku; *a*, 2*a*, and

* The seismograms obtained at Mt. Tsukuba, Mizusawa, Shanghai, Taichu, Hōkoto, etc. also indicated the preliminary tremor.

T denoting as usual the amplitude, double-amplitude, and the complete period of vibration, respectively.

Osaka. (Fig. 2.) EW component (Multiplication = 20). Natural oscillation period of the horizontal pendulum=27 sec. The earthquake began quite suddenly with a large quick displacement of 2.9 mm, towards W, followed by a counter motion of 4.9 mm, towards E, this latter being the absolute maximum. The vibrations were active for $2^m\ 20^s$, being composed of the following 3 sets:—

$T=$ 3.7 sec. (larger vibrations),
$T=$ 5.7 „ (smaller „).
$T=27.0$ „ $2a=6.5$ mm (pend. oscillations).

The motion was distinct for further $5^m\ 15^s$:—$T=4.9$ sec.

The diagram furnished by a horizontal pendulum apparatus, whose recording drum rotated once in 24 hours, (Fig. 3), also indicated no preliminary tremor.

Kobe. (Fig. 4.) NS component (Multiplication=20). Natural oscillation period of the horizontal pendulum=25 sec. The earthquake began suddenly with a large vibration, of $T=36$ sec. whose two displacements were as follows:—

$$\begin{cases} \text{1st} \ldots\ldots\ldots\ a=1.3 \text{ mm, towards N,} \\ \text{2nd} \ldots\ldots\ldots 2a=1.7 \text{ „ , „ S;} \end{cases}$$

the latter being the maximum of this sort of motion.

The motion was most active for the first $3^m\ 15^s$ and consisted of the following 3 sets of vibrations:—

$$\begin{cases} T=\ 3.1 \text{ sec.} \\ T=11.1 \text{ sec., } 2a=2.1 \text{ mm (this max. occurred 38 sec. after the commencement).} \\ T=24.5 \text{ sec., } 2a=3.3 \text{ mm (pend. oscil.)} \end{cases}$$

Thereafter the motion gradually diminished, the movements being as follows:—

$$\begin{cases} T=11.3 \text{ sec.}, & 2a=0.58 \text{ mm} \\ T=\ 4.0\ \text{,, (?)}, & 2a=\text{small}. \end{cases}$$

Towards the end:—T=11.1 sec.

Taihoku. (Fig. 13.) EW Component (Multiplication=10). Natural oscillation period of the horizontal pendulum=23 sec.

The preliminary tremor lasted $3^m\ 0^s$, the movements at the very commencement being as follows:—

1st .... a=0.11 mm, towards W;
2nd ....$2a$=0.19 ,, , ,, E.

The average periods were:—T=4.0 sec., T=2.1 sec.

The principal portion lasted $6^m\ 55^s$, the movements at the commencement being as follows:—

$$\begin{cases} \text{1st} \ldots\ldots\ldots\ a=0.65 \text{ mm, towards W;} \\ \text{2nd} \ldots\ldots\ldots 2a=2.55\ \text{,, , ,, E;} \\ \text{3rd} \ldots\ldots\ldots 2a=2.40\ \text{,, , ,, W.} \end{cases}$$

The subsequent motion was much smaller.

5. *Vibration at the Commencement of the Earthquake.*

(i) *Observations at Ōsaka, Kōbe, Kyōto and Tadotsu.* The 1st vibration of the earthquake motion recorded at the 4 stations of Ōsaka, Kōbe, Kyōto, and Tadotsu, which are situated westwards from the origin, and where the preliminary tremor was entirely absent or unduly large, was as follows :—

Station.	1st Displacement.	2nd Displacement.	Remarks.
Ōsaka (EW).	mm 2.83, towards W.	mm 4.83, towards E.	Quick vib. This was the abs. max.
Kōbe (NS).	1.23 ,, N.	1.73 ,, S.	Quick vibration.
Kyōto (EW)	1.75 ,, W.	2.68 ,, E.	Slow vib. mixed with quick movements.
Tadotsu (EW).	0.90 ,, W.	2.00 ,, E.	Slow vibration.

Combining the observations at Ōsaka and Kōbe, which are near to each other, we find the following resultant motion:—

$\begin{cases} \text{1st displacement.........} & a=3.08 \text{ mm, towards N } 67^\circ \text{ W.} \\ \text{2nd} \quad ,, \quad \text{........} & 2a=5.14 \quad ,, \quad ,, \quad \text{S } 71^\circ \text{ E.} \end{cases}$

As the earthquake origin lies to the S 80° E of Ōsaka the initial vibration may be regarded as due to the *longitudinal wave*, and took place in a direction parallel to the line joining the places of observation with the centre of disturbance ; the 1st displacement being directed away from the latter. The initial displacement in the E W component at Kyōto and Tadotsu was also directed towards W. It may be here noted that some microseismographs with a large multiplication ratio and a short natural oscillation period, say, of 2 or 3 seconds, are, on the occasion of a sharp local shock or large earthquake, usually thrown at once into big proper oscillations, thereby indicating apparently or *diagrammatically* the maxmium movement at the commencement. With the observations at Ōsaka and Kōbe, however, the movements recorded were really those of the ground, their periods being the same at the two places, namely, 3.7 and 3.6 sec., and quite different from the natural oscillation periods of the horizontal pendulums, which were 27 and 25 sec. respectively.

(ii) *Observation at Tōkyo.* The observation at Tōkyo, where the preliminary tremor, was clearly indicated is also very interesting, as it gives the directions of vibrations at the very commencement of the motion, and of the principal portion. Taking suitably the mean value of the EW component motion, we find:—

1st displacement at the commencement of the preliminary tremor............$a=0.60$ mm, towards W ;

the simultaneous NS and vertical components being as follows:—

$$\begin{cases} a=1.05 \text{ mm, towards S,} \\ a=0.54 \text{ ,, , downwards.} \end{cases}$$

These give for the resultant horizontal motion the following:—

initial (prel. tremor) displacement.........$a=1.2$ mm, towards S 30° W.

The counter horizontal motion was:—

$2a=3.2$ mm, towards N 22° E.

Taking the mean from the 1st and the counter displacements, we find:—

direction of the initial vibration.........S 26° W—N 26° E.

As now the origin of the earthquake was to the S 65° E of Tōkyo, it will be observed that the direction of motion of the vibration at the commencement of the preliminary tremor was exactly at right angles to the line joining Tōkyo with the origin; that is to say, the preliminary tremor *in this particular instance* belonged to the *transverse wave.*

Turning now our attention to the *principal portion,* we obtain the following mean result for the 1st displacement of the large vibration at the commencement:—

1st displacement.........$a=9.9$ mm, towards N58°W.

The counter EW component motion was 13 mm towards E, the two displacements of the vertical motion being respectively $a=2.3$ mm downwards, and $2a=3.8$ mm upwards. The NS component pointer, however, unfortunately went out of the smoked paper and did not record the 2nd displacement and the subsequent movements. It will be observed that the 1st displacement of the principal portion was nearly parallel to the line joining the

earthquake origin with Tōkyo, thus belonging to the *longitudinal wave.*

(iii) *EW Component Observations at Mito, Ishinomaki and Miyako.* The seismogram at Mito, which is situated about 100 km to the NW of Tōkyo, was similar in character to those obtained at the latter place. Thus we have:—

Mito (EW)
- 1st displacement at the commencement of the preliminary tremor=0.41 mm, towards W;
- 1st displacement (*a*) at the commencement of the principal portion=5.4 mm, towards W.
- 2nd displacement (2*a*), or the counter motion of the preceding=11.8 mm, towards E.

The directions of the movements at the commencement of the EW component principal portion obtained at Ishinomaki and Miyako, both situated in the north-eastern part of the Main Island, were the same as at Tōkyo, being directed towards W and towards E respectively.

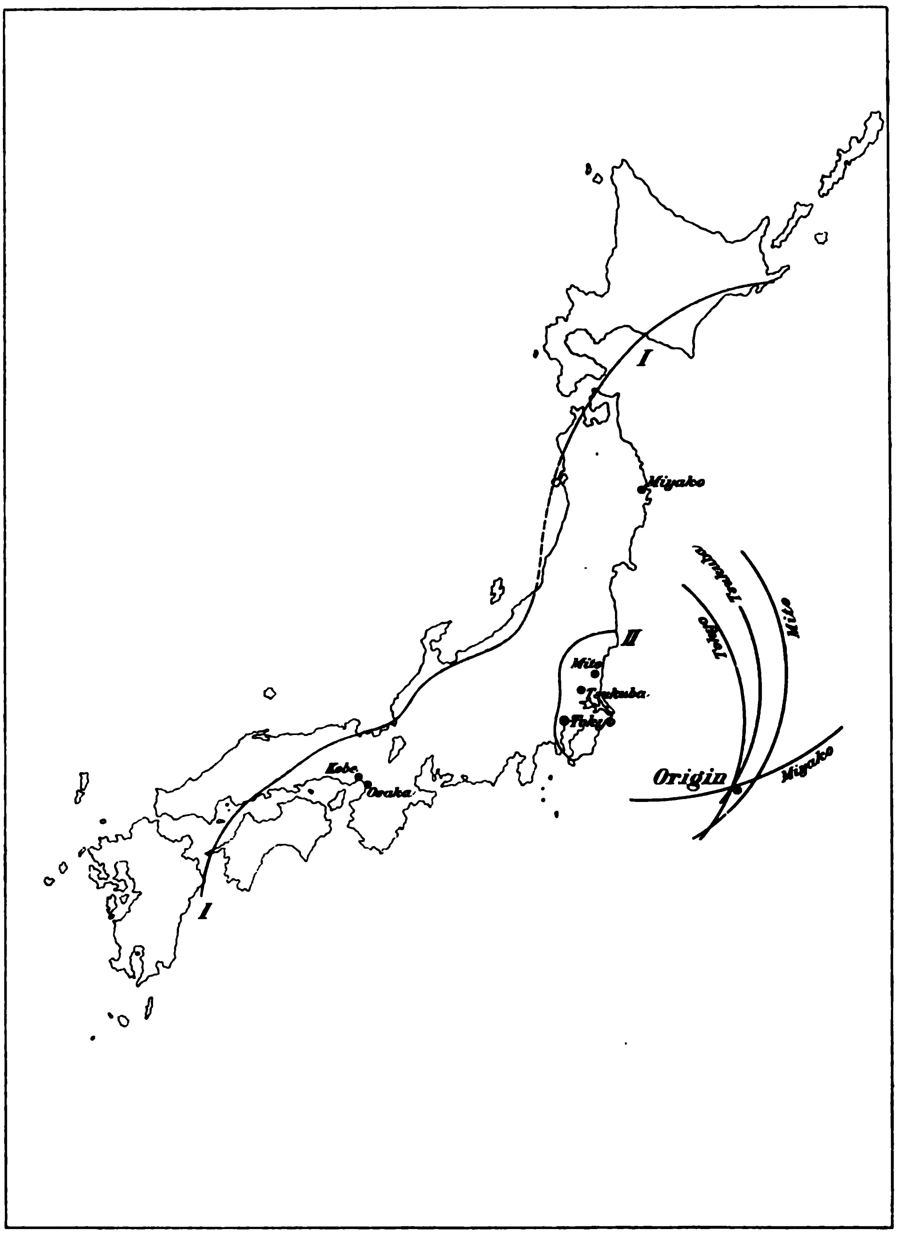
6. *Transverse and Longitudinal Vibrations.* By comparing the observation at Tōkyo with those at Ōsaka and Kōbe, we arrive at the conclusion that the first vibrations in the preliminary tremor registered in the former place were due to the *transverse wave,* while the large principal vibrations at the very commencement of the earthquake motion registered at the two latter places (as well as Kyōto and Tadotsu) were due to the *longitudinal wave.* To explain these peculiar relations, we may suppose that the preliminary tremor consisted, from some cause, mainly of the transverse vibrations in a nearly N—S direction. Such movements would give the preliminary tremor at Tōkyo in nearly the N—S direction, but would be overtaken, along the path towards Ōsaka and Kōbe, by the longitudinal wave, whose

propagation velocity is greater than that of the transverse wave; the result being that at the last mentioned places we got first the large vibrations constituting the principal portion, due to the longitudinal wave.

Fig. 1. Map of Japan, showing the Isoseismal Lines and the Position of the Origin of the Earthquake of Jan. 21, 1906.

(I) Boundary of the area of slight motion.

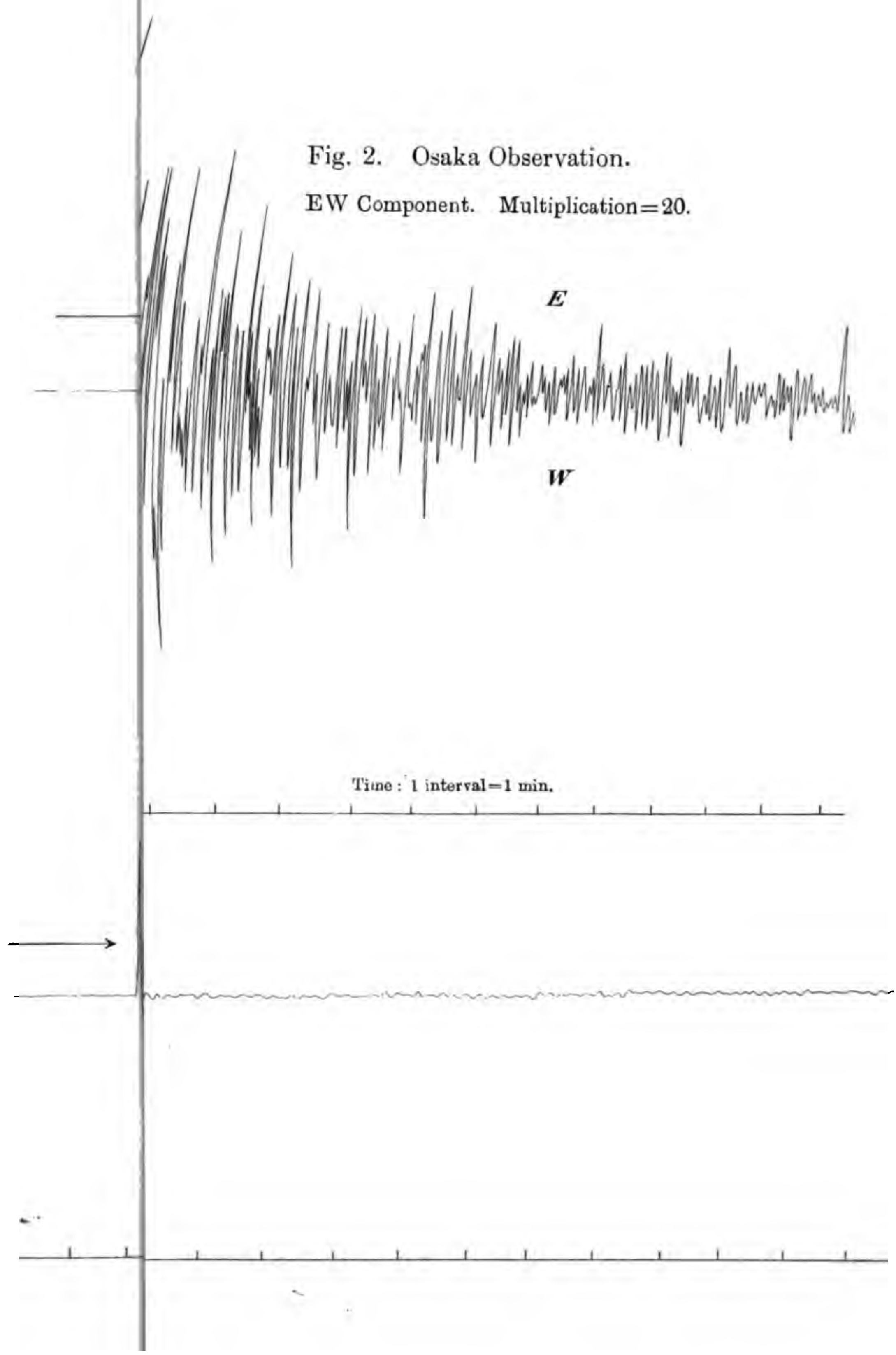
(II) " " " " of strong motion.



ime).

Fig. 2. Osaka Observation.

EW Component. Multiplication=20.



Earthquake of Jan. 21, 1906. PL. XXXIV.

a.........Commencement.

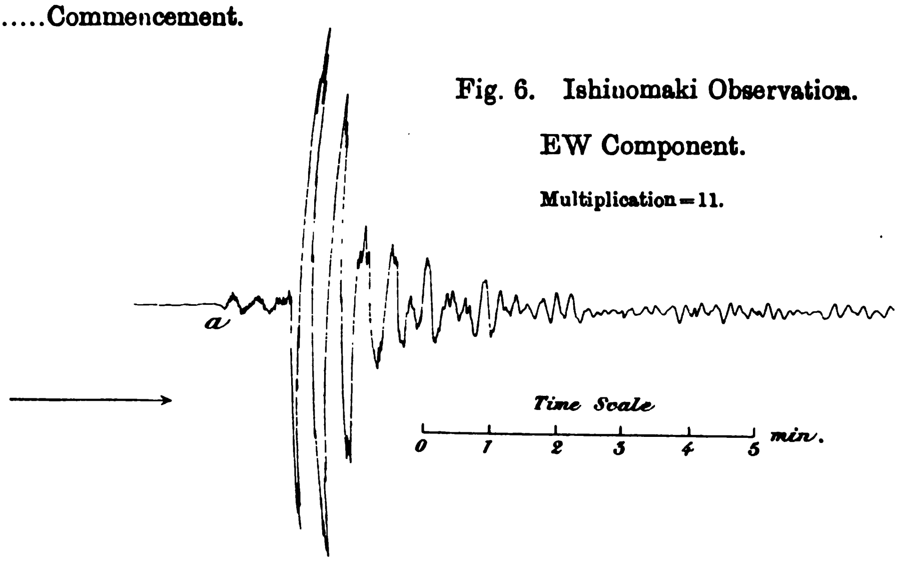


Fig. 6. Ishinomaki Observation.

EW Component.

Multiplication = 11.

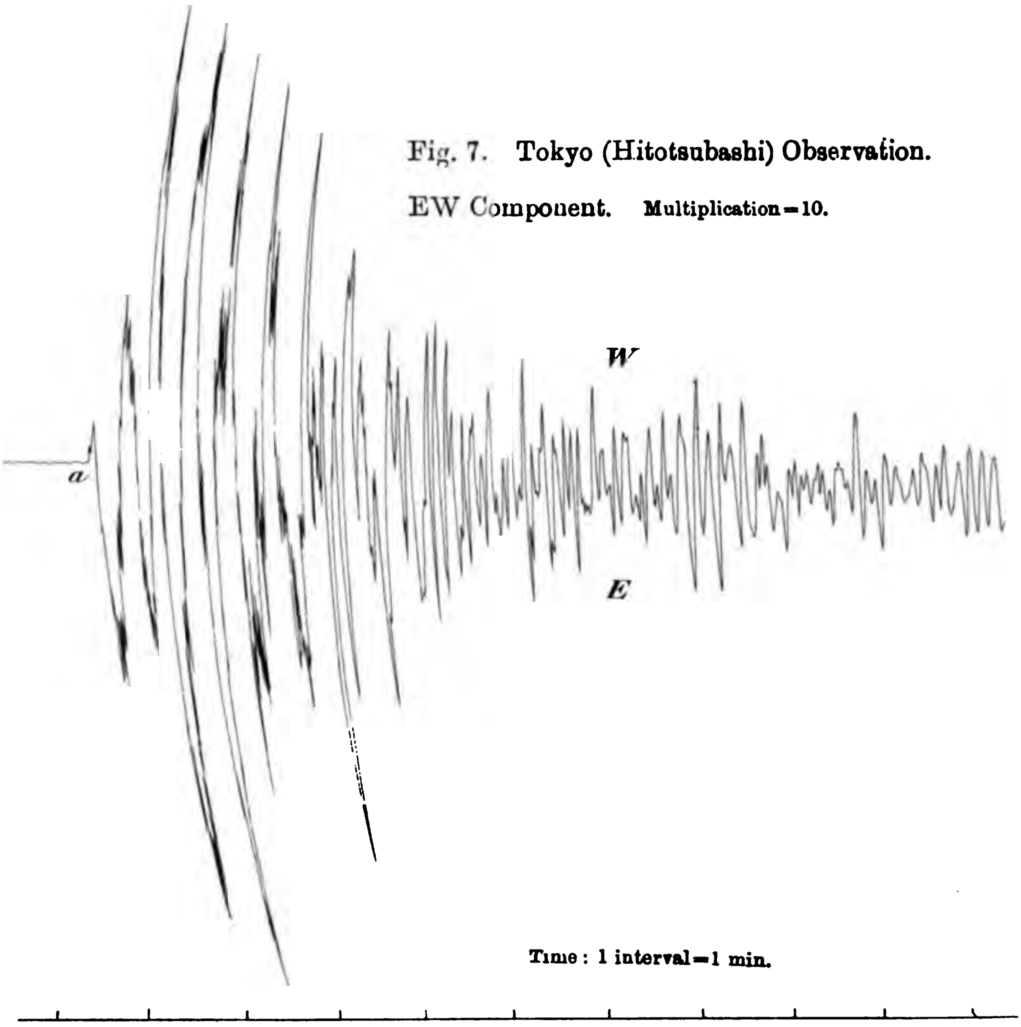


Fig. 7. Tokyo (Hitotsubashi) Observation.

EW Component. Multiplication = 10.

Time: 1 interval = 1 min.

Earthquake of Jan. 21, 1906.

a.........Commencement.

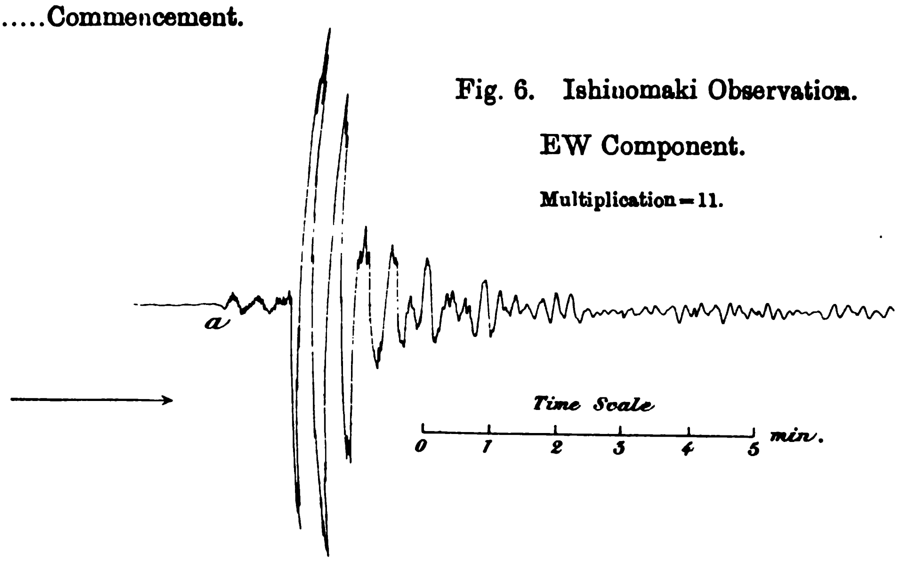


Fig. 6. Ishinomaki Observation.

EW Component.

Multiplication = 11.

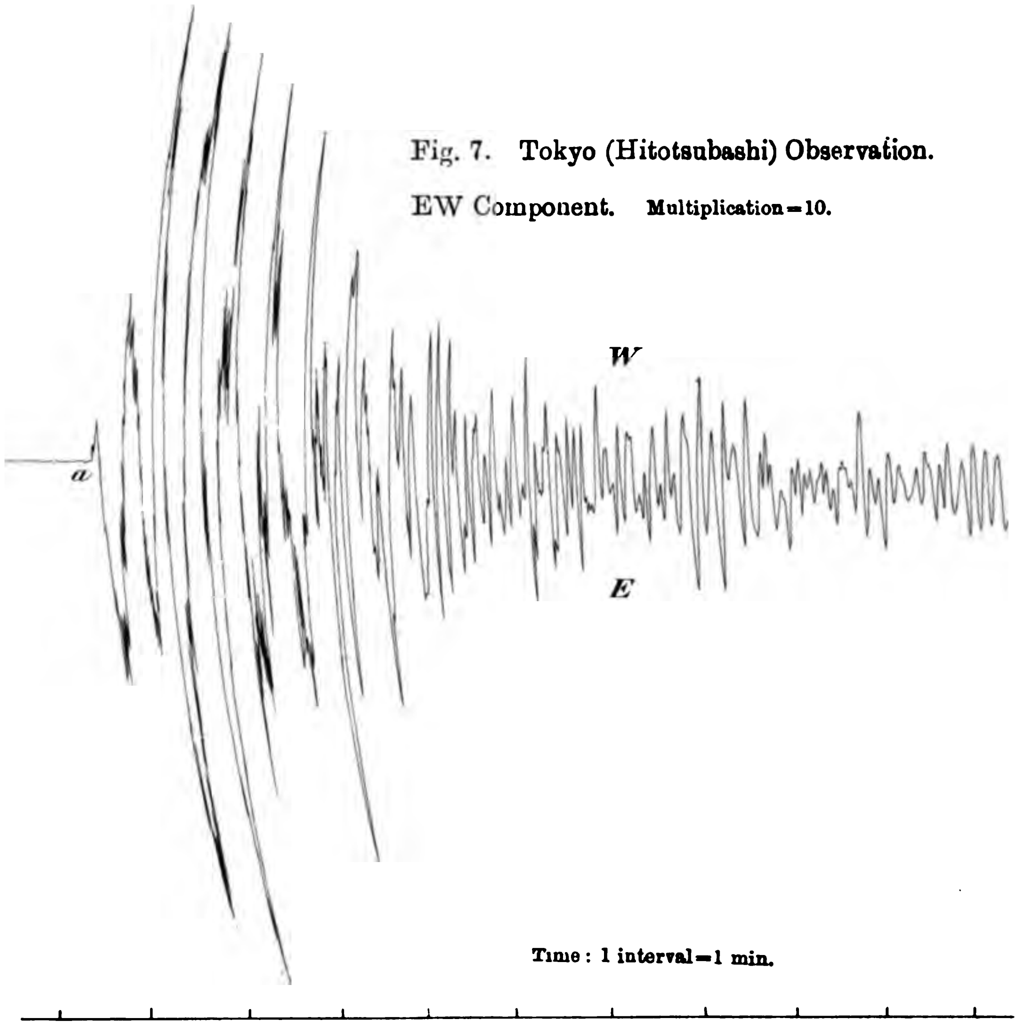


Fig. 7. Tokyo (Hitotsubashi) Observation.

EW Component. Multiplication = 10.

Time : 1 interval = 1 min.

Earthquake of Jan. 21, 1906.

Observation in Tokyo (Hongo).

Time : 1 interval = 1 min.

a.........**Commencement.**

(×) *Pointer went out.*

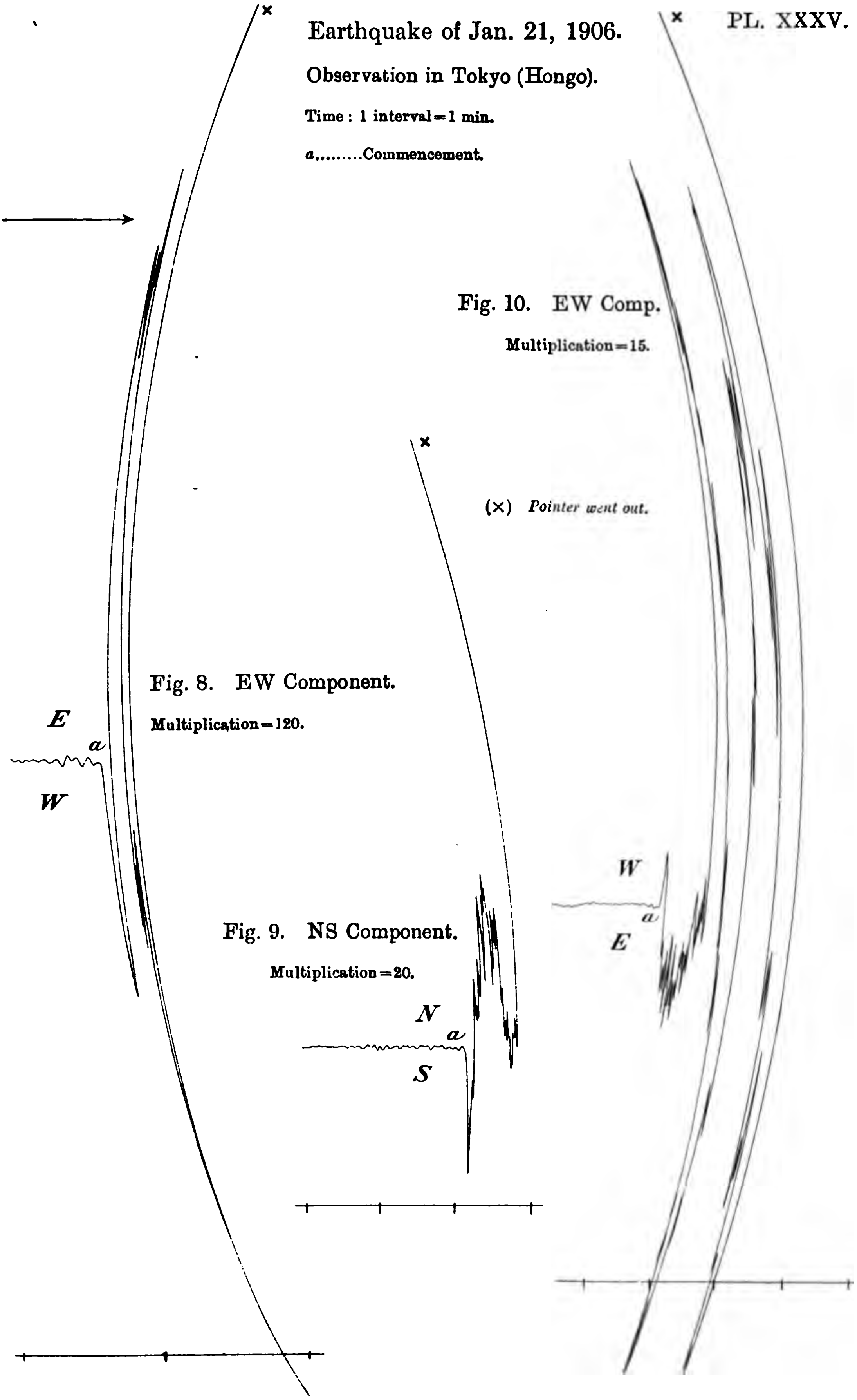


Fig. 8. EW Component.

Multiplication = 120.

Fig. 9. NS Component.

Multiplication = 20.

Fig. 10. EW Comp.

Multiplication = 15.

Earthquake of Jan. 21, 1906; 10.50 p.m. (Japan Time).

Fig. 11 and Fig. 12. Vertical component, observed in Tokyo.

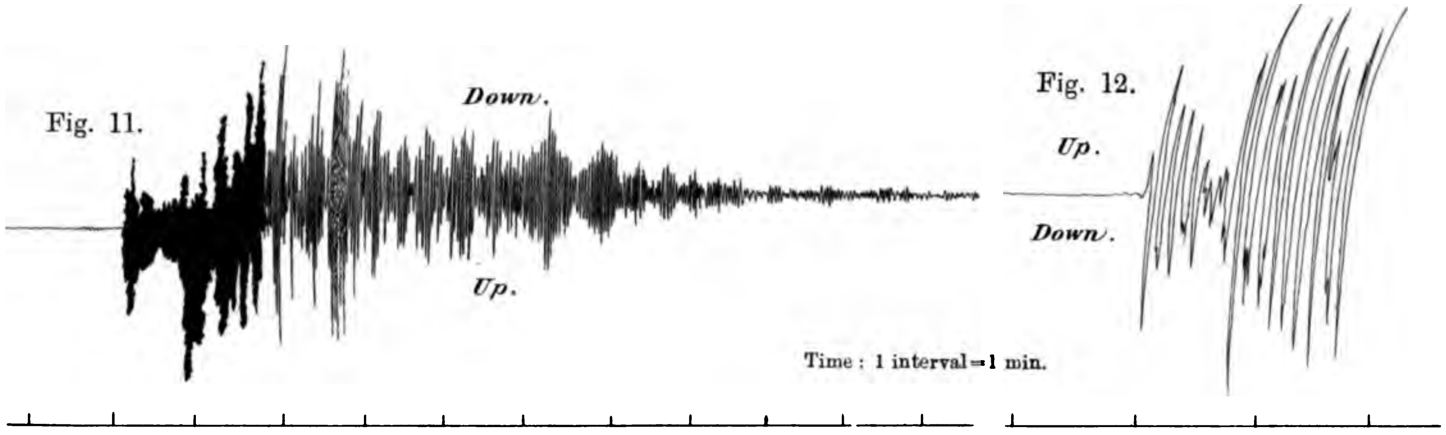
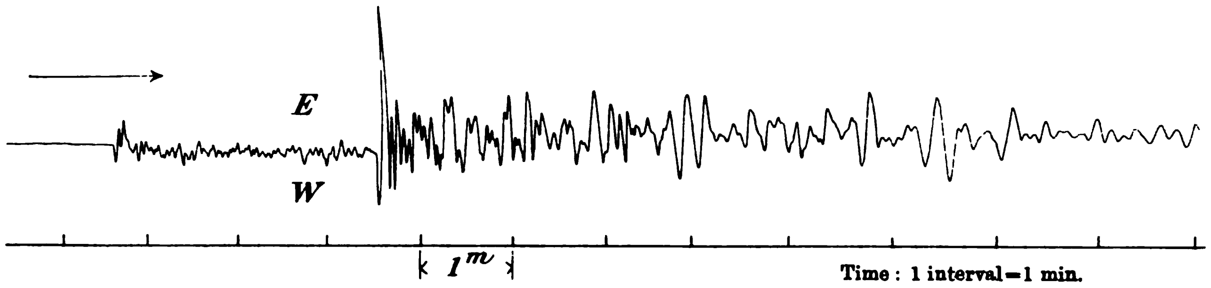


Fig. 13. Observation at Taihoku, Formosa.

EW Component. Multiplication = 10.



Vibrations of a Railway Bridge Pier.

By

F. Omori, Sc.D.,

Member of the Imperial Earthquake Investigation Committee.

A preliminary series of the measurement of the vibrations of railway bridge piers was carried on in 1901, the first report on this subject having been given in the *Publications of the Earthquake Investigation Committee*, No. 12. I have continued these measurements with my horizontal tremor recorder, in which the two horizontal component pointers had each a magnification of 10 to 50 times, the registration being made in ink on white paper driven by rollers. The diagrams obtained were, as shown in Pl. XXXIX, very good.

Tone-gawa Bridge, near Toride Station, Nippon Railway. This single-track (3′ 6″ gauge) bridge consists of eight 200′ Double Warren trusses and twenty-two 60′ plate girders. On Aug. 27, 1904, I have made a series of measurements of the vibrations of the pier between the 7th and 9th 200′ trusses,* (counted from the Tokyo end of the bridge). The pier experimented on was built of brick and had a total height of 94′.2, of which 29′.35 was above the river bed and had a thickness of 10′, while the remaining 64′.86 formed the well and had a thickness of 12′; the depth of water being about 10′. † The tremor recorder was set up on the

* This is one of the piers experimented on in 1901.

† The elevation and plan of the pier is given in the *Publications*, No. 12.

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* This is one of the piers experimented on in 1901.

† The elevation and plan of the pier is given in the *Publications*, No. 12.

top of the pier; Pl. XXXVIII being a picture of the instrument. Pl. XXXIX is one of the diagrams obtained, and magnifies 30 times both the longitudinal and transverse vibrations; these two latter being respectively the movements of the pier perpendicular and parallel to its face or plane. The motion was caused, in the case under consideration, by an up train consisting of a locomotive and 44 goods wagons at a slow speed. As will be seen from Pl. XXXIX, the greatest transverse vibrations occurred not at the moment of the transit of the locomotive, but when the end car of the train was just passing over the pier; there being a series of maximum movements, which corresponded to the successive piers, on account of the transmission of the transverse motion of the different piers through the means of the girders. Again, the longitudinal vibration was by no means small, as ought to be. In fact, as shown in my previous paper, a pier which rises from soft and muddy river bed does not vibrate with its base, that is to say, junction with the well as the centre or fixed point; the real position of the latter being a considerable distance below the ground surface. In our case, the centre of vibration is 40′ or 50′ deep; the pier (and the well) with the girders thus forming virtually a tall brick column, 60′ or 70′ in height, with heavy top load. Hence it is natural that the pier should vibrate parallel to its face as well as at right angles to the latter. The elements of motion were as follows:—

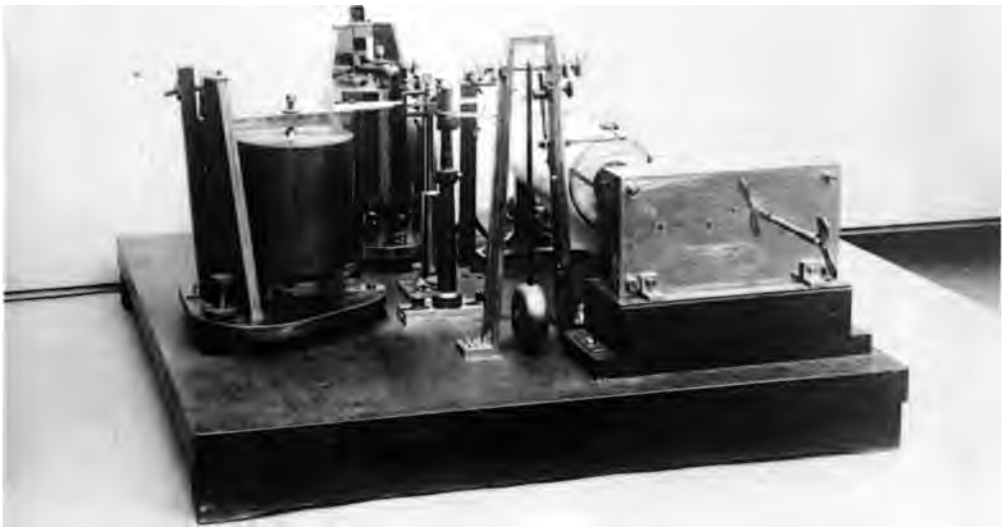
Transverse Vibration.

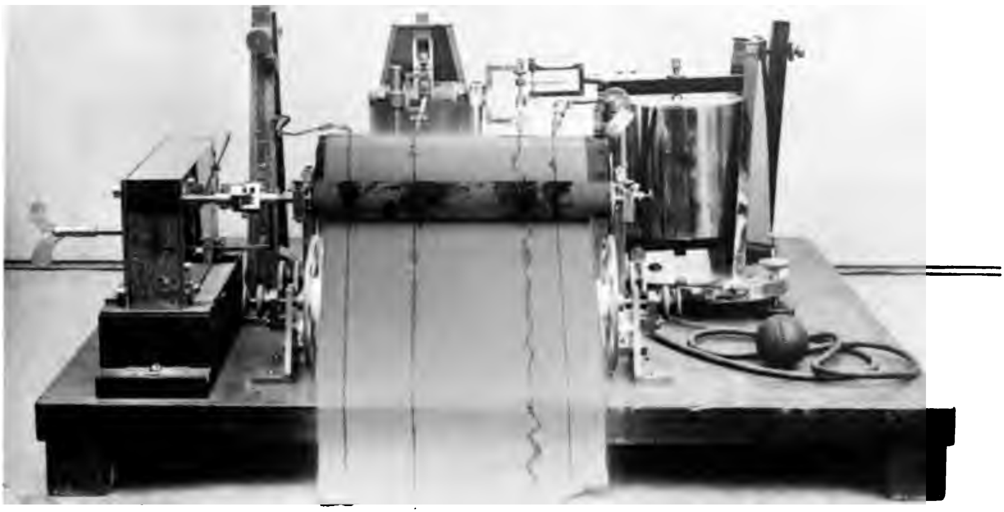
$$\begin{cases} \text{Complete Period}=0.39 \text{ sec., max. motion}=0.63 \text{ mm;} \\ \qquad\quad ,, \qquad =0.18 \ ,, \ , \qquad ,, \qquad =0.08 \ ,, \end{cases}$$

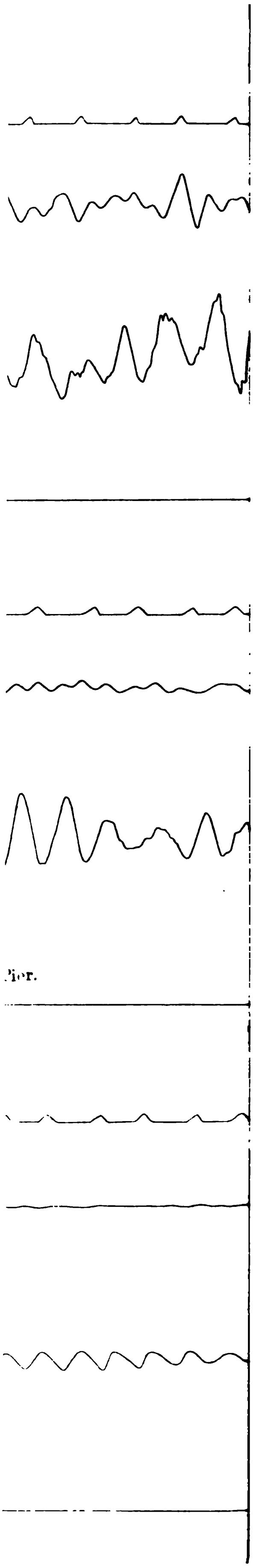
Longitudinal Vibration.

Complete Period=0.22 sec., max. motion=0.33 mm,

Horizontal Vibration Recorder.







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there being also some traces of slow movements of period of 0.7 sec., due probably to the effect of the lateral vibration of the 200′ girders. Towards the end, the movements became small and regular, there being the following two sets of motion:—

$$\begin{cases} \text{Complete Period} = 0.37 \text{ sec.} \\ \quad\quad\text{,,} \quad\quad = 0.24 \text{ ,,} . \end{cases}$$

Thus in this case the amplitude of the longitudinal vibration was half of that of the transverse vibration. But as the periods of the principal movements in these two components were 0.39 and 0.22 sec. respectively, it comes out that the acceleration of the longitudinal vibration was nearly double that of the transverse. If we further take into consideration the fact that the breadth of the pier was not less than twice the thickness, the great importance of the longitudinal vibration in its relation to the strength of the pier will be readily recognised.

A full report on the measurement of the vibrations of the different brick and iron piers will be given in a future number of the *Publications.*

On a Method of Suppressing Air Tremors Occurring in Milne H. P. Seismograms.

By

A. Imamura, Sc. D.,

Extraordinary Member of the Imperial Earthquake Investigation Committee.

The principal disturbing cause in Milne H. P. Seismograms is probably the appearance of the so-called *air tremors*, especially in cold weather during night and early morning, which obscure the earthquake motion occurring at these times. This disturbance is known as an effect of convection current of the air within the instrument case, which cools in its upper part in consequence of quick radiation, while the air near the record-receiver and forming the middle layer in the case becomes comparatively warm under the influence of the lighted lamp.

Our instrument room is bounded with a metallic covering within a small building ($1.5 \times 1.8 \times 2.0$ m.) with wooden walls and a metallic roof.* This construction was evidently favorable for the occurrence of the disturbance in question, for the air tremors which occurred very much during the colder months could not be completely suppressed even under the contrivance due to Mr. Moos.† After carrying on the observation in this way for several winters, I have arrived finally at a means which seems to be fairly satisfactory.

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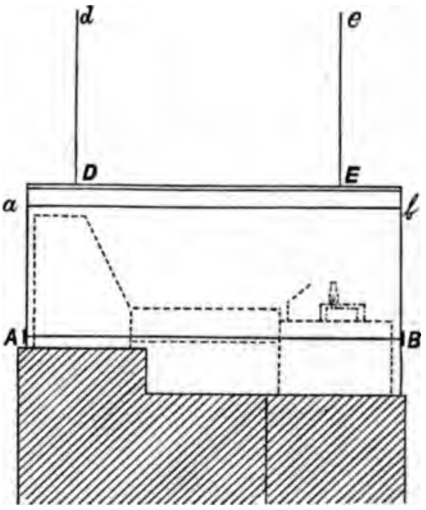
* See the *Publications of the Imp. Earthq. Inv. Comm.*, No. 16, p. 1.

† See Prof. Milne: Fourth Report of the British Association Seismological Committee.

Figs. 1–2 show the front and lateral views of the new arrangement. The shaded part is the brick pier upon which the instrument case represented with dotted lines is mounted. Over this inner case, another wooden covering shown in the figures with full lines was newly added. The new case is divided into two

Fig. 1.



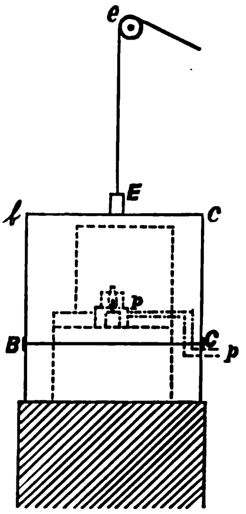


Fig. 2.

parts; the upper one, which fits closely to the lower along the lines AB and BC, can be lifted up by means of two suspenders Dd and Ee. The lamp is also covered with a small metallic case from which a chimney projects out. A fresh supply of air is to be drawn through the pipe pp from outside, while the colder air within the outer covering can escape from the lower side of the latter. Further, the covering is provided at the front side with a door and a window as the gates for the record-receiver and the lamp respectively.

The object of the present arrangement is to warm the upper layer of air within the two coverings and consequently to prevent the raising of convection current within the inner covering. Since

the instrument was covered with the outer case at the beginning of the last month it has not almost been affected by the air tremors, notwithstanding the season was hitherto an unfavorable one. During this experiment the free vibration period of the boom was kept at 15 sec., but perhaps it can advantageously be increased to 20 sec. or more without being much affected by any residual air tremors.

Tokyo.

April 1907.

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Note on the Kashgar (Turkestan) Earthquake of Aug. 22, 1902.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

1. ***Position of the Earthquake Origin.*** According to a map showing the isoseismal lines of the earthquake in question, given by Mr. A. Voznessensky in No. 4 of the "Bulletin Sismique de l'Observatoire Magnétique et Météorologique d'Irkoutsk," the earthquake origin seems to be situated at about *latitude* 39°42′ N, and *longitude* 76°E. This position has been assumed to be the source of disturbance in the calculation of the epicentral distances of different stations.

The times are, unless otherwise stated, always given in G.M.T.

2. ***Approximate Time*** **($=t_0$)** ***of Earthquake Occurrence at the Origin.***

(i) The epicentral distance of Taschkent, which was nearest the centre of disturbance is only 5°21′, the time of occurrence of the earthquake there being $3^h02^m12^s$. If we assume the mean transit velocity between the origin and Taschkent to be 6 km per sec.,* the time required by the vibrations of the 1st preliminary tremor in passing through that distance would be 91 sec., giving the following value for the time of occurrence at the origin:

$$t_0=3^h00^m41^s$$

* The "Publications," No. 13.

(ii) Taking the observation made in Tokyo, and using the formula

$t_0 = t_1 - 1.165\, y_1$*,

we find:—

t_1 = Time of occurrence in Tokyo = $3^h 09^m 33^s$

y_1 = Duration of 1st Prel. Tremor = $6^m 44^s$

$t_0 = 3^h 00^m 43^s$

Taking the mean of the two above values of t_0, we obtain:—
Time of earthquake occurrence at the origin,

$t_0 = \mathbf{3^h 00^m 42^s}$ (G.M.T.)

3. ***Time (t_1) of Eq. Occurrence at the different Stations.*** The following table gives the latitude, longitude, and epicentral distance of, and the time of the earthquake occurrence at, each of the 36 different seismological stations, where the shaking was instrumentally observed.

Table I. Turkestan Earthquake: Epicentral Distance and Time of Occurrence.

Place.	Position. Latitude.		Position. Longitude.		Epicentral Distance $=x$.	Time of Eq ke Occurrence (G.M.T.) $=t_1$.
Origin	**39° 42′**	N	**76°**	E	....	**3^h 00^m 42^s**
(i) Taschkent	41° 19′ 31″	N	69° 17′ 42″	E	5° 21′	3^h 02^m 12^s
Colaba (Bombay) ...	18 53 45	N	72 48 56	E	20 59	05 24
Irkutsk	52 16 --	N	104 18 33	E	23 07	05 24
Tiflis	41 43 08	N	44 47 51	E	23 36	05 14
(ii) *Mean*	....		....		**22 34**	**3 05 21**
(iii) Kodaikanal	10 13 50	N	77 27 46	E	29 30	3 04 48
Nikolajev	46 58 18	N	31 58 27	E	32 24	07 00

* The "Bulletin," No. 1.

Table I. *Cont.*

Place.	Position. Latitude.				Longitude.				Epicentral Distance $=x$.		Time of Eqke Occurrence (G.M.T.) $=t_1$.		
Pavlovsk	59°	41′	—″	N	30°	29′	15″	E	34°	35′	3ʰ	07ᵐ	48
(iv) *Mean*	...				...				**33**	**30**	**3**	**07**	**24**
Budapest	47	22	29	N	19	03	55	E	41	02	3	09	20
Laibach	46	03	—	N	14	31	—	E	44	22		06	50
Leipzig	51	20	06	N	12	23	30	E	44	34		08	01
Triest	45	38	45	N	13	45	45	E	44	59		08	17
Hamburg	53	33	55	N	10	01	19	E	45	35		08	55
Ischia	40	40	—	N	13	59	—	E	46	22		10	05
Manila	14	34	41	N	120	58	33	E	46	34		09	04
Catania	37	29	—	N	15	04	—	E	46	44		08	59
Ōsaka	34	42	—	N	135	31	—	E	46	48		09	04
Rocca di papa	41	46	—	N	12	42	—	E	46	54		08	30
Quarto-Castells	43	49	11	N	11	13	11	E	47	15		08	53
Strassburg	48	35	—	N	7	46	10	E	48	06		10	00
Pavia	45	11		N	9	09		E	48	13		08	52
Tokyo	35	42	29	N	139	45	53	E	49	32		09	33
Uccle	50	47	53	N	4	21	44	E	49	35		09	06
(v) *Mean*	...				...				**46**	**26**	**3**	**08**	**54**
Edinburgh	55	57	23	N	3	10	46	W	52	24	3	09	30
Shide	50	42		N	1	19		W	53	02		10	12
Paisley	55	51		N	4	25		W	53	05		10	10
Liverpool	53	24	04	N	3	04	18	W	53	09	...		
Batavia	6	08		S	106	50		E	53	56		09	54
(vi) *Mean*	...				...				**53**	**07**	**3**	**09**	**54**
(vii) San Fernando	36	27	40	N	6	12	19	W	62	23	3	09	06

Table I. *Cont.*

Place.	Position. Latitude.		Position. Longitude.		Epicentral Distance $=x$.	Time of Eqke Occurrence (G.M.T.) $=t_1$.
Perth (W.A.)	31° 52′ —″	S	115° 50′ —″	E	80° 32′	3ʰ 13ᵐ 36ˢ
Cape Town............	33 56 03	S	18 28 41	E	90 47	14 48
Victoria, B.C.	48 27 —	N	123 22 —	W	90 12	16 00
Toronto*...............	43 39 36	N	79 23 24	W	93 43	25 48
Baltimore*	39 17 48	N	76 37 12	W	97 08	24 30
(viii) *Mean* .... (*Excluded)	....		....		**87 10**	**3 14 48**
Christchurch	43 31 50	S	172 37 18	E	120 17	3 20 36
Wellington*	41 17 —	S	174 47 —	E	120 39	29 00
(ix) *Mean*............... (*Excepted)	....		....		**120 17**	**3 20 36**
(x) Cordova............	31 26 —	S	64 12 —	W	146 52	3 19 30

Propagation Velocity v_1, calculated by "Difference Method." The mean group values of the epicentral distance (x) and the corresponding time (t_1) of earthquake occurrence are, according to the above table, as follows:—

(i)	$x=$ 5° 21′ ;	$t_1=3^h02^m12^s$	(1 station)
(ii)	22 34	3 05 21	(3 stations)
(iii)	29 30	3 04 48 (?)	(1 „)
(iv)	33 30	3 07 24	(2 „)
(v)	**46 26**	**3 08 54**	(15 „)
(vi)	53 07	3 09 54	(5 „)
(vii)	62 23	3 09 06 (?)	(1 „)
(viii)	87 10	3 14 48	(5 „)
(ix)	120 17	3 20 36	(1 „)
(x)	146 52	3 19 30	(1 „)

The values of the velocity v_1 calculated by combining the group (v) with the others are given in the following table:—

Velocity v_1 Calculated by "Difference Method."

Combination of Groups.	δx	δt_1	v_1
(v)—(iv)	12° 55′	$1^m 30^s$	15.9 km/sec.
„ —(ii)	23 52	3 33	12.4
„ —(i)	41 05	6 42	11.4
(vi)—(v)	6 41	1 00	12.4
(viii)— „	40 44	5 54	12.8
{(ix) (x)}— „	87 09	11 09	14.4

The average of the velocity, deduced from the 6 different values contained in the above table is

$$v_1 = \mathbf{13.2} \text{ km/sec.}$$

This is to be regarded only as a rough approximation.

4. ***Duration of the 1st Preliminary Tremor.*** Table II gives for a number of stations the epicentral distance and the duration (y_1) of the 1st preliminary tremor.

Table II. Turkestan Earthquake: Duration of the 1st Preliminary Tremor.

Place.	Epicentral Distance $=x$.	Duration of 1st Prel. Tremor $=y_1$.
Colaba (Bombay)	20° 59′	$3^m 54^s$
Kodaikanal (Madras)	29 30	5 06
Pavlovsk	34 35	6 06
Mean	**28 21**	**5 02**
Leipzig	44 34	7 35
Ōsaka	46 48	7 12

Table II. *Cont.*

Place.	Epicentral Distance $=x$.	Duration of 1st Prel. Tremor $=y_1$.
Quarto-Castello	47° 15′	7m 39s
Tokyo	49 32	6 44
Mean	**47 02**	**7 18**
Edinburgh	52 24	8 00
Batavia	53 56	8 00
Mean	**53 10**	**8 00**
San Fernando	62 23	10 12
Cape Town	90 47	9 30
Baltimore	97 08	8 48
Christchurch	120 17	20 36
Cordova	145 52	21 42
Mean	**133 35**	**21 09**

Taking provisionally only the 4 mean group values of the x and the corresponding y_1 contained in Table II, and calculating by the method of Least Squares the constants of a linear equation assumed between these two quantities, we obtain the following result:—

$$x^{km}=11.8y_1^{sec}-60^{km}$$

(for x between 28° and 134°)

The above equation, which is to be regarded as being only roughly approximate, relates to the observation of the Turkestan earthquake at different places. (Compare with a similar equation for the San Francisco earthquake of April 18, 1906, given in the *Bulletin*, No. 1.)

Tilting of the Ground during a Storm.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

1. In the "Publications of the Earthquake Investigation Committee", No. 21, I have described an EW horizontal pendulum or "tiltometer" diagram obtained in Tokyo during a storm, on Oct. 10th and 11th, 1904, which shows the tilting of the ground to an amount of $3\frac{1}{2}''$. Fig. 1, Pl. XL, illustrates a similar case of the tilting of the ground observed on Jan. 10 and 11, 1906, in Tokyo, with the EW component horizontal pendulum, whose recording cylinder makes one revolution in 24 hours. The instrument, which is set up in the brick "Earthquake-proof House" in the University Compound (Hongō), is of the following specifications:—

Length of the strut, or the horizontal distance between the pendulum axis and the centre of the heavy bob$=L=75^{cm}$.

Period of the pendulum when suspended vertically$=T_0=1.74$ sec.

Period of the horiz. pendulum as actually set up$=T=33$ sec.

Multiplication ratio of the pointer$=n=20$.

1mm displacement of the writing index$=$

$$r=L\times n\times sin\ 1''\times\frac{T^2}{T_0^2}=0.''0385$$

2. ***The Weather at Tokyo on Jan. 10 and 11, 1906.**** The following table gives the hourly values at Tokyo on Jan. 10th and

* The times are given in 1st Normal Japan Time, or that of longitude 135° E.

11th, 1906, of the atmospheric pressure, wind velocity, and the amount of precipitation.

Barometric Pressure,* Wind Velocity, and Precipitation.

Tokyo, Jan. 10 and 11, 1906.

Hour.	Jan. 10th.			Jan. 11th.		
	Barometric Pressure.	Wind Velocity.	Precipitation.	Barometric Pressure.	Wind Velocity.	Precipitation.
	mm. 700+	m/sec.	mm.	mm. 700+	m/sec.	mm.
1 A.M.	69.6	2.8	—	53.1	3.3	1.7
2	69.4	2.2	—	51.1	2.8	1.1
3	69.3	3.3	—	49.3	2.2	3.9
4	68.6	3.3	—	46.5	3.3	4.3
5	68.3	2 4	—	44.6	3.5	8.4
6	68.1	3.7	—	42.7	5.0	**22.0**
7	67.9	3.7	—	**42.3**	9.0	6.7
8	67.8	3.7	—	42.6	7.9	0.3
9	67.4	2.8	0.0	42.9	3.3	—
10	67.2	2.2	0.0	43.5	2.6	0.0
11	66.0	0.8	—	43.9	2.8	—
Noon.	64.3	0.8	—	43.8	1.6	—
1 P.M.	63.3	0.8	—	43.4	5.6	—
2	62.6	1.1	—	44.6	7.4	—
3	62.2	1.1	—	45.1	11.0	—
4	61.6	1.6	—	46.3	8.5	—
5	60.9	0.9	—	46.7	8.8	—
6	60.3	1.1	0.0	47.6	10.3	—
7	59.8	1.6	0.0	48.3	9.0	—
8	59.0	2.4	—	48.4	10.8	—
9	57.7	1.8	0.0	49.2	9.4	—
10	57.1	1.8	0.6	49.6	6.3	—
11	55.8	2.4	0.2	49.2	5.6	—
Midnight.	54.2	2.4	0.2	49.2	3.3	—

(* Reduced only to the freezing point. Reduction to standard gravity $= -0.63^{mm}$, that to mean sea level $= +2.01^{mm}$.)

As will be seen from the above table, the barometric pressure was 769.6 mm at 1 a.m., on the 10th, thence gradually decreasing to 744.6 mm at 5 a.m., on the 11th. The pressure, which reached the minimum of 742.3 mm at 7 a.m. on the latter day, remained low and less than 744 mm for the next 6 hours. The wind velocity reached a maximum value of 9.0 m/sec. nearly at the moment of the lowest barometric pressure, although greater values of 10.3 to 11 m/sec. were reached at between 3 and 8 p.m. of the 11th. The maximum hourly amount of the precipitation was 22 mm and occurred between 5 and 6 a.m., on the 11th.

The cyclone, which caused the storm in question, first appeared in the morning of the 10th off the south-eastern coast of China and already approached the west coast of Kyushu on the afternoon of the same day, thence progressing in an E E N direction along the Inland Sea. The centre of depression passed, at 7 a.m. on the 11th, between Tokyo and Yokohama, thence moving over the Pacific in a NNE direction, and approaching the north-eastern part of Hokkaido on the afternoon of the same day. The lowest barometric pressure of 724.6 mm was registered at 10 and 11 p.m., on the 11th, at the meteorological observatory of Shana (Kurile Islands).

3. *Tilting of the Ground and Pulsatory Oscillations.* The "pulsatory oscillations" began to appear gradually at 4 p.m., on the 10th, accompanied by a slight tilting of the ground towards E. At $4^h 56^m$ a.m. on the 11th, (marked *a* in Fig. 1), the rate of the eastward inclination began to become quicker; the maximum displacement of the pointer of the *tiltometer* in the same direction being reached at $5^h 56^m$ a.m., on the same morning. This moment is marked *b* in the figure, the actual trace on the diagram amounting to 21 mm, which is equivalent to $0''.81$. At the same time the

pulsatory oscillations became very active, and reached a maximum range of 0.2 mm. Then there began the tilting of the ground towards W, and the maximum displacement of the pointer (marked *c* in the figure) in that direction occurring at $8^h\,31^m$ a.m. on the 11th. The total or double amplitude of the tilting oscillation amounted to 74.6 mm or 2.″87.

After $8^h\,31^m$ the tilting began to turn towards E again, the pulsatory oscillations becoming at the same time still more active.

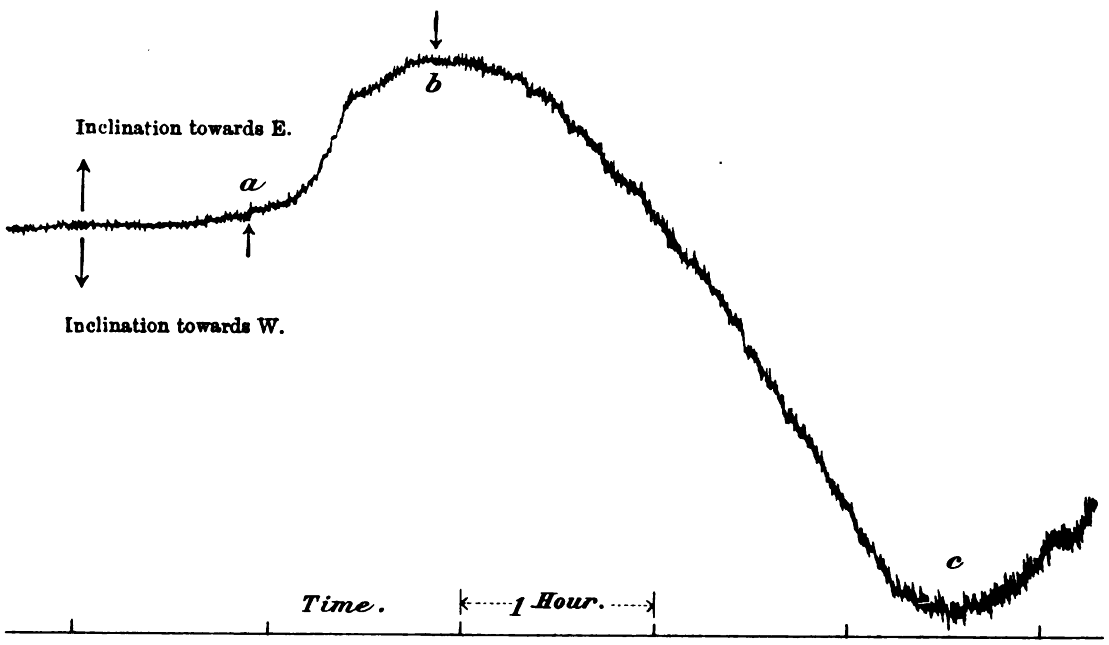
The pointer reached its normal position at about $3^h\,15^m$ p.m., on the 11th; the pulsatory oscillations continuing active (maximum range=0.25 mm) till that time.

Fig. 2 and Fig. 3 give the records furnished by a horizontal pendulum tromometer of multiplication=120, also set up in the "Earthquake-proof House", for a few minutes interval, respectively at about 2 and 4 a.m., on the 11th. The elements of motion were as follows:—

$$\begin{cases} 2 \text{ a.m. (11th)} \ldots\ldots \text{max. range} = 0.17 \text{ mm, period} = 6.2 \text{ sec.} \\ 4 \quad ,, \qquad\qquad ,, \quad = 0.15 \ ,, \ , \quad ,, \quad 6.4 \ ,, \ . \end{cases}$$

4. From §§ 2 and 3, it will be seen that the extreme elongation towards E (*b* in Fig. 1) coincided with the epoch of the greatest rainfall, and that the remarkable westward tilting from *b* to *c* nearly coincided with the time interval during which the atmospheric pressure was lowest, namely, between 6 and 9 a.m. (on the 11th). Now the existence of a barometric depression on Musashi, Shimosa and Hitachi plain, or the district lying to the east and north-east of Tokyo, would cause this part of the earth's surface to rise up, the consequence being that there ought to be a westward inclination (*bc*) at Tokyo and the neighbourhood. A similar explanation is applicable to the eastward inclination (*ab*).

Fig. 1. EW Tiltometer Record. Jan. 11, 1906; Hongō, Tokyo.



Pulsatory Oscillations, Observed at Hongō, Tokyo. Jan. 11, 1906. EW Component.
Multiplication = 120.

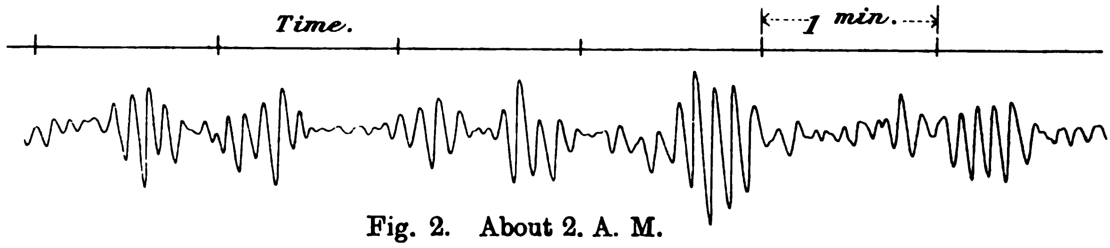


Fig. 2. About 2. A. M.

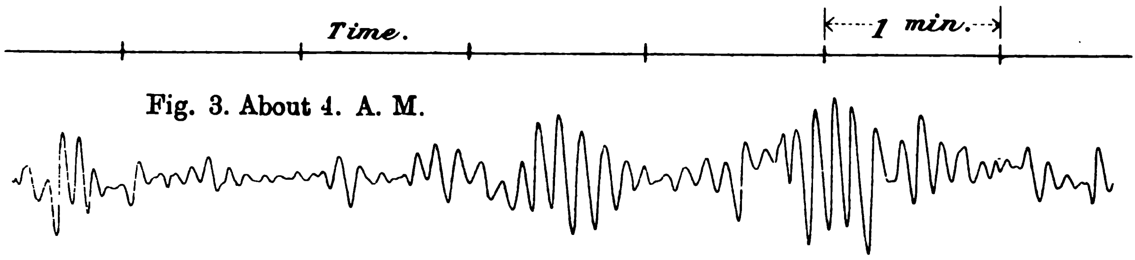


Fig. 3. About 4. A. M.

The demonstration suggested above is rather opposite to that used for the case of the tilting observed in Tokyo on Oct. 10 and 11, 1904. The discrepancy probably lies in the fact that on the latter occasion, the depression moved entirely over the Pacific at a distance of several hundred km. from the coast, while in the present case the track of the cyclone was entirely over the land, from its first entrance in Kyushu to its passage into the ocean at the coast of Hitachi.

Tiltometer observations of the effects of the barometric pressure simultaneously in two rectangular horizontal directions seem to be very interesting in connection with the question of the rigidity of the earth's crust.

The Deflection and Vibration of Railway Bridges. 2nd Paper.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

1. ***Introduction.*** In No. 9 of the *Publications of the Earthquake Investigation Committee in Foreign Languages,* I have given an account of the measurements of the deflection and vibration of eleven railway bridges, with description of the instruments employed. Since then these experiments have been greatly extended, and in the course of 1901 and 1902, the movements of the 24 different girders and trusses on the Government, the Nippon, and the Kwansei Railways have been examined. All the trusses were *through* in construction except the two similar 105′ Pratt trusses of the 5th Aizawa-*gawa* and the Kami Usui-*gawa* bridges which were *deck* in construction. All of these bridges, most of which are constructed according to the Imp. Jap. Gov. Railway Standard, are for single track. In a few cases, the vibration of the bridge piers have also been recorded. The present note gives a tabular statement of the results of these measurements; the full report will be given in a future number of the *Publications.*

2. ***Instruments.*** The measurement of the deflection and vibration of the bridge trusses and girders was done with the same instruments and in exactly the same way as in the preceding series of experiments For taking the direct measurement of the total amount of the deflection, however, a new self recording arrange-

ment was designed, whose mechanical details an given in Pl. XLI. This instrument consists essentially of a strong wooden board (a), 5 inches broad and some 3 feet long, which is fixed by means of proper bolts or hooks (b) to the girder or the bottom chord of the truss. From the middle of the plate, rises a wooden post (c) about 1′ tall, whose top serves as the fulcrum for the lever (de). One end of the latter is stretched by three similar powerful spiral springs (k) fixed vertically to the plate (a); while from the other end, (e), a square piece of wood (f) is suspended, which is to be tightly stretched by means of a weight (g), (not shown in the figure) suspended with a steel wire or tape. To the inner side of the wood piece (d) is fixed by a screw a small thin rectangular piece of wood, (h), about 1″×5″ in size, against which presses the point of a pencil (i) contained in a guiding tube (j) fixed to the base plate. The tube (j) contains at its end a small spiral spring which presses the pencil (i) forward. Thus, when a train passes over the girder or truss, the latter is deflected and bent down; while the small plate (h) remains always in its position, on account of the stretching due to the weight (g) and the springs (k).

The pencil (i) therefore traces in the natural size the amount of the total deflection (i. e. statical deflection and maximum vertical vibration combined) on the plate (h). The latter is after each experiment to be substitued by a new one. Except for the case of mountain torrent, this method gave generally satisfactory results, no matter how deep the water was; the weight (g) consisting of a cylindrical weight of lead furnished with three small feet, which together weigh about 15 kg. The following are some of the cases, in which the deflection was measured both directly by the above mentioned contrivance, and by the vertical motion seismograph (deflectometer) set up on the bridge itself:—

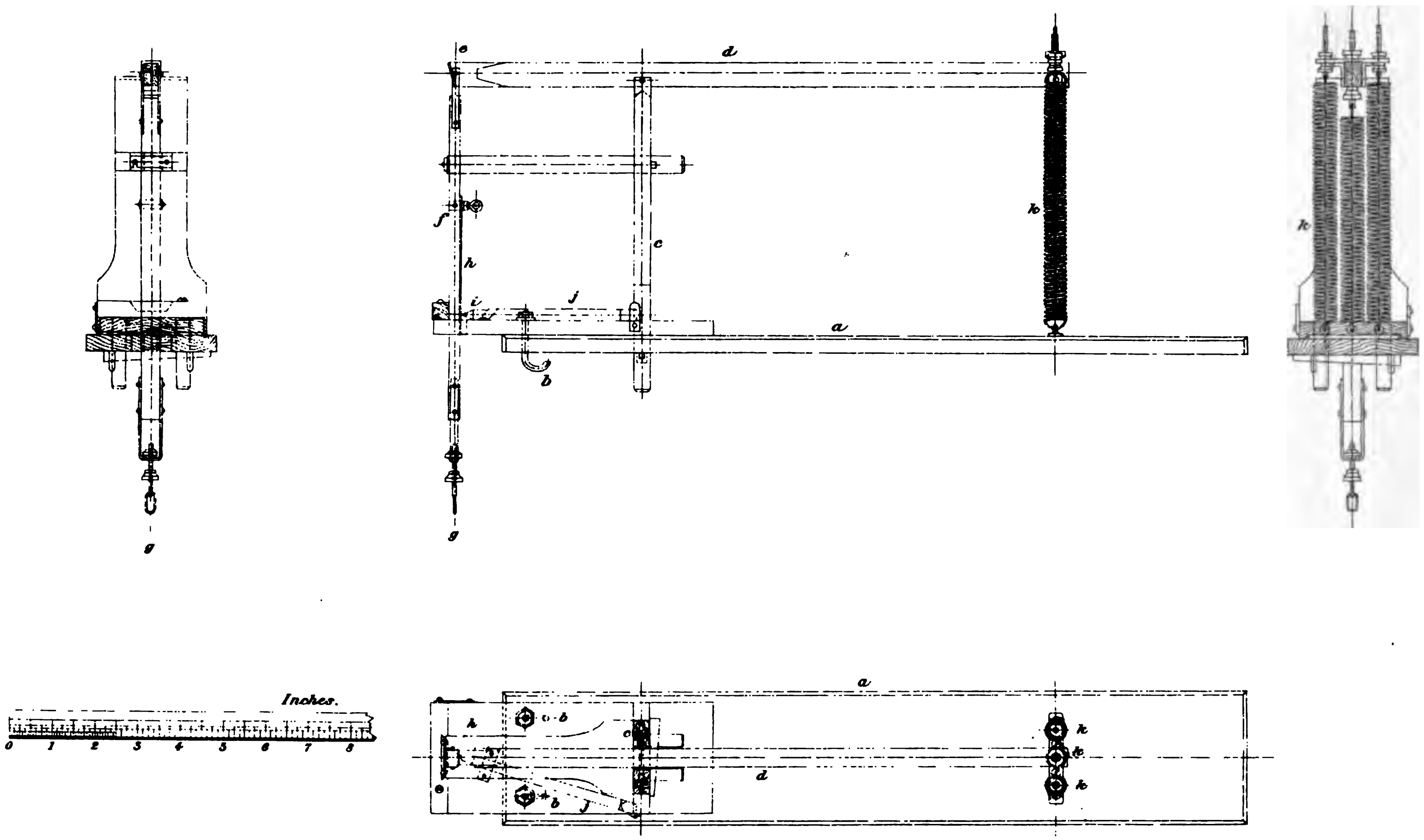
Bridge.		Deflection measured directly.	Deflection measured by vert. mot. seismograph.	Remarks.
Ōi-*gawa*. (Tokaido Ry.)	200′ Double Warren Gird.	24.0 mm	26.2 mm	Passenger train, with 2 engines Nos. 608 and 2 at head.
Do.		19.0	21.0	Mixed train, with 2 engines Nos. 610 and 113 at head.
Ibi-*gawa* (Kwansei Ry.)	"	18.0	17.4	Passenger train, Engine No. 44.
Do.		19.0	17.5	Passenger train, Engine No. 41.
Mean.		**20.0**	**20.5**	

3. Deflection and Vibration of the Bridge Girders and Trusses. Table II, which embodies the results of the second series of the deflection and vibration measurements, gives for each of the bridge girders and trusses the different elements of the movement; the experiment having been, except in a few cases, repeated 2 to 21 times. Table III gives a general summary of the results of measurements contained in Table II, namely, the absolutely greatest and mean maximum values of the deflection, double amplitude, and period, for each case. Table I gives a list of the locomotives which passed over the different bridges during the experiments. The terms *deflection*, and *vertical*, *transverse* and *longitudinal vibrations*, which are used in the same senses as heretofore and refer to the middle of the bottom side of a girder or truss, are defined as follows:—

The *deflection* is the total amount of bending, which is equivalent to the sum of the statical bending and the maximum vibration amplitude.

The *vertical vibration* is the up and down quick movement,

A Contrivance for measuring the Deflection of a Bridge.



whose period depends on each girder or truss; while the *transverse* and the *longitudinal vibrations* are the movements, which take place in the horizontal plane, and whose directions are respectively perpendicular and parallel to the length of the bridge. For each class of vibrations, the range of motion, or double amplitude, and the period (that is to say, the complete period) are denoted respectively by the symbols 2a and T.

The values of the deflections given in Tables II and III have been obtained as follows:—(1), measured by the deflectometer alone in the cases of a 70′ plate girder of the Tone-*gawa* (Maebashi), the three 100′ Warren girders of the Kuji-*gawa*, the 2nd Sakawa-*gawa* and the 3rd Sakawa-*gawa* bridges, the 120′ Pratt truss of the Ibi-*gawa* bridge, the two similar 105′ Pratt deck trusses (up line) of the 5th Aizawa-*gawa* and the Kami-Usui-*gawa* bridges, and the 200′ Pratt truss of the Kizu-*gawa* bridge; (2), measured directly by the contrivance before described, in the cases of the 20′ plate girder of the Tone-*gawa* bridge (Toride), the 70′ plate girder of the Kizu-*gawa* bridge, the 100′ Warren girder (one nearest the Kasagi end) of the Kizu-*gawa* bridge, the 105′ Pratt truss (down line) of the 5th Aizawa-*gawa* bridge, a 200′ Double Warren girder (Truss No. 14) of the Ōi-*gawa* bridge, the 200′ bow-string truss of the 3rd Aizawa-*gawa* bridge, and a 200′ Double Warren girder (No. 1) of the Tone-*gawa* bridge (Toride); and, (3), measured both by the deflectometer and directly by the same contrivance as in (3), in the remaining 4 cases.

The period of the longitudinal vibration which was generally too quick to be distinctly measured by our instrument, is not given in the tables.

The *asterisks*, affixed in Table III to the names of some of the bridges signify that the values of the deflection and

the vibrations given there are those caused by the passage of the heaviest engine or train which pass over those bridges in the present state of the traffic on the different Japanese railways. In Table III, the absolutely greatest among the different values of a given element of motion in each column are printed in fat letters.

A photographic picture of the contrivance for directly measuring the deflection, described in § 2, is given in Pl. XLII.

TABLE I.—LIST OF THE LOCOMOTIVES.‡

No.	Class.	Total Weight	Weight of Tender.	No.	Class.	Total Weight	Weight of Tender.
	NIPPON RAILWAY.*						
		T C Q	T C Q			T C lbs	T C lbs
38	Tank Engine	33. 8. 2	—	513	Tender Engine	70. 16. 118	26. 13. 26
62	" "	44. 15. 0	—	515	" "	" " "	" " "
123	" "	38. 19. 3	—	524	" "	" " "	" " "
209	Tender "	55. 16. 0	24. 10. 0	527	" "	" " "	" " "
211	" "	" " "	" " "	535	" "	80. 0. 122	26. 13. 26
		lbs	lbs				
508	" "	70. 16. 118	26. 13. 26	553	Tank "	39. 9. 12	—
510	" "	" " "	" " "	555	" "	" " "	—
511	" "	" " "	" " "				
	KWANSAI RAILWAY.						
		T C Q	T C Q			T C Q	T C Q
24	Tender Engine	62. 17. 3	25. 17. 3	36	Tender Engine	64. 0. 0	23. 10. 0
27	Tank "	36. 2. 0	—	38	" "	" " "	" " "
29	" "	" " "	—	39	" "	" " "	" " "
30	Tender "	64. 0. 0	23. 10. 0	40	" "	54. 4. 0	18. 10. 0
31	" "	" " "	" " "	41	" "	" " "	" " "
33	" "	" " "	" " "	42	" "	" " "	" " "
34	" "	" " "	" " "	44	" "	" " "	" " "
35	" "	" " "	" " "				
	GOVERNMENT RAILWAYS.						
		T C Q	T C Q			T C Q	T C Q
2	Tender Engine	42. 14. 0	17. 6. 0	272	Tender Engine	59. 8. 0	22. 2. 0
74	Tank "	45. 9. 2	—	278	" "	" " "	" " "
113	" "	33. 8. 2	—	289	" "	" " "	" " "
187	Tender "	60. 19. 0	22. 0. 0	299	Tank "	48. 9. 0	—
188	" "	" " "	" " "	324	" "	" " "	—
189	" "	" " "	" " "	325	" "	" " "	—
190	" "	" " "	" " "	505	Abt "	53. 12. 0	—
191	" "	" " "	" " "	605	Tender "	46. 17. 0	19. 10. 0
193	" "	" " "	" " "	606	" "	" " "	" " "
194	" "	" " "	" " "	608	" "	" " "	" " "
197	" "	" " "	" " "	610	" "	" " "	" " "
199	" "	" " "	" " "	612	" "	" " "	" " "
200	" "	" " "	" " "	634	" "	" " "	" " "
203	" "	" " "	" " "	640	" "	" " "	" " "

‡ *Total weight* is the weight of the engine and tender.

* The Nippon Railway has recently been nationalized.

TABLE II. DEFLECTION AND VIBRATION

River.	Bridge Girder or Truss.	Deflection. Instrumentally measured. (mm)	Deflection. Directly measured (mm)	Deflection. Mean. (mm)	Vertical Vibration. 2a (mm)	Vertical Vibration. T (s)
Tone (Toride) (Nippon Ry.)	20′ Plate Girder	—	2.1	—	—	—
		—	2.9	—	—	—
	60′ „ „	10.8	—	—	1.0	0.21
		8.8	—	—	1.2	0.24
		11.1	—	—	1.5	0.22
		9.1	10.3=($\frac{13}{32}$″)	9.7	1.0	0.22
		8.0	10.3=(„)	9.2	1.2	0.26
		—	9.5=($\frac{3}{8}$″)	—	—	—
Kuji (Ōmika) (Nippon Ry.)	60′ „ „	—	12.5	—	—	—
		—	12.4	—	—	—
		—	12.4	—	—	—
Tone (Mayebashi) (Nippon Ry.)	70′ „ „	8.8	—	—	2.6	0.90
		7.5	—	—	1.7	0.22
		—	—	—	1.5	0.19
		8.8	—	—	2.0	0.21
		9.9	—	—	1.8	0.21
Kizu (Kasagi) (Kwansai Ry.)	70′ „ „	—	16.3	—	—	—
		—	14.5	—	—	—
		—	15.5	—	—	—
Kizu (Ōmika) (Nippon Ry.)	100′ Warren Girder	14.3	—	—	3.5	0.35
		16.4	—	—	5.6	0.34
		—	—	—	0.9	0.34
		17.8	—	—	5.4	0.34
(No. 2) Sakawa (Yamakita) (Gov. Ry.)	100′ „	14.7	—	—	3.2	0.35
		11.6	—	—	5.6	0.27
		13.3	—	—	3.2	0.32
(No. 3) Sakawa (Yamakita) (Gov. Ry.)	100′ „	15.4	—	—	5.1	0.29

OF RAILWAY BRIDGES IN JAPAN.

Transverse Vibration. 2a (mm)	Transverse Vibration. T (s)	Longitudinal Vibration. 2a (mm)	Time taken by Locomotive in passing over the Girder or Truss. (s)	No. of Locomotive.	Train.
—	—	—	—	209	Up, Passenger Train.
—	—	—	—	515	Down, „ „
—	—	—	3.8	553	Up, Goods „
—	—	—	3.0	123	Down, „ „
—	—	—	4.0	527	Up, Mixed „
—	—	—	3.2	62	Down, Goods „
—	—	—	4.2	555	„ „ „
—	—	—	—	513	„ Mixed „
—	—	—	—	535	Up, Goods „
—	—	—	—	508	„ Passenger „
—	—	—	—	524	Down, „ „
—	—	—	2.2	38	„ Mixed „
3.5	0.43	0.2	2.6	„	Up, „ „
2.0	0.32	1.0	—	„	Down, Passenger „
3.2	0.40	Faint.	2.6	„	Up, Mixed „
5.0	0.37	0.4	2.6	„	Down, „ „
—	—	—	—	31	Up, Mixed „
—	—	—	—	24	Down, Goods „
—	—	—	—	36	„ Express.
8.6	0.63	0.7	2.9	511	Down, Passenger „
10.0	0.99	0.9	3.2	508	Up, „ „
6.3	1.06	0.4	6.9	535	„ Goods „
10.0	0.61	0.7	3.4	524	Down, Passenger „
6.5	0.76	1.3	4.4	194 and 191, in series.	Up, Goods „
5.9	Vibration very quick.	2.7	2.3	199	„ Passenger „
10.2	1.09	—	3.8	193 and 197, in series.	„ Goods „
—	—	—	4.0	190 and 272, in series.	„ Passenger „

TABLE II.

River.	Bridge Girder or Truss.	Deflection. Instrumentally measured. (mm)	Directly measured. (mm)	Mean. (mm)	Vertical Vibration. 2a (mm)	T (s)
Kizu (Kasagi) (Kwansei Ry.)	100' Warren Girder. (on Nagoya side).	12.0	—	—	3.7	0.30
		10.2	—	—	2.7	0.28
		9.3	—	—	2.3	0.27
		9.8	—	—	2.8	0.28
		11.3	—	—	2.1	0.25
		13.3	—	—	4.7	0.25
		—	11.5	—	—	—
		—	10.2	—	—	—
		—	10.4	—	—	—
		—	10.6	—	—	—
		—	9.2	—	—	—
		—	9.5	—	—	—
		—	14.0	—	—	—
" (Do.)	100' Warren Girder. (on Kasagi side).	—	10.2	—	—	—
		—	9.8	—	—	—
Ibi (Nagashima) (Do.)	120' Pratt Truss.	7.2	—	—	1.6	0.25
		8.0	—	—	1.2	0.28
		5.3	—	—	1.0	0.21
No. 5. Aizawa (Oyama) (Gov. Ry.)	105' Pratt Truss Deck.	25.4	—	—	5.8	0.33
		22.4	—	—	4.4	0.31
" (Do.)	105' (")	—	17.5	—	—	—
		—	15.0	—	—	—
Kami-Usui (Matsuida) (Do.)	105' (")	14.7	—	—	4.9	—
		17.2	—	—	6.8	0.28
		18.2	—	—	6.3	0.32
		17.7	—	—	4.3	0.28
		15.4	—	—	4.4	0.33

CONT.

Transverse Vibration. 2a (mm)	T (s)	Longitudinal Vibration. 2a (mm)	Time taken by Locomotive in passing over the Girder or Truss. (s)	No. of Locomotive.	Train.
—	—	—	2.3	29	Up, Passenger Train, 11 Carriages
—	—	—	2.8	33	„ „ „ , 16 „
—	—	—	3.9	38	Down, Goods „ , 6 Wagons
—	—	—	3.4	33	Up, Passenger „ , 11 Carriages
—	—	—	3.4	38	„ , Goods „ , 11 Wagons
—	—	—	2.5	35	Down, Passenger „ , 10 Carriages
—	—	—	—	39	Up, „ „ , 11 „
—	—	—	—	30	Down, „ „ , 10 „
—	—	—	—	35	„ , Goods „ , 11 Wagons
—	—	—	—	33	„ , Passenger „ , 12 Carriages
—	—	—	—	30	Up, „ „ , 11 „
—	—	—	—	35	„ , Goods „ , 11 Wagons
—	—	—	—	31	Down, Passenger „ , 10 Carriages
—	—	—	—	34	Up, Goods „ , 4 Wagons
—	—	—	—	39	„ , Passenger „ , 10 Carriages
—	—	—	4.4	40	Down, Passenger „ , 10 Carriages
—	—	—	4.6	41	Up, Mixed „ , { Pass., 6 Cars. Goods, 6 Wags.
—	—	—	4.3	27	Down, „ „ , { Pass., 6 Cars. Goods, 6 Wags.
—	—	—	4.6	{ 193 and 197, in series.	Up, Goods, „ , 26 Wagons
—	—	—	4.0	{ 189 and 289, in series.	„ , Passenger „ , 20 Carriages
—	—	—	—	200	Down, Passenger „ , 9 Carriages
—	—	—	—	193	„ , Goods „ , 31 Wagons
—	—	—	—	74	„ , „ „ , 10 Wagons
7.8	1.01	0.7	3.2	299	Up, „ „ , 12 „
6.2	0.99	1.1	3.3	325	Down, Mixed „ , { Pass., 7 Cars. Goods, 3 Wags.
7.7	1.32	0.9	3.3	74	Up, „ „ , { Pass., 6 Cars. Goods, 4 Wags.
5.4	0.99	0.7	3.6	299	Down, Goods „ , 13 Wagons

TABLE II.

River.	Bridge Girder or Truss.	Deflection. Instrumentally measured. (mm)	Deflection. Directly measured. (mm)	Deflection. Mean. (mm)	Vertical Vibration. 2a (mm)	Vertical Vibration. T (s)
Kami-Usui (Matsuida) (Gov. Ry.)	105' (Pratt Truss Deck)	17.4	—	—	5.8	0.25
		16.7	—	—	5.7	0.28
		—	—	—	5.5	0.28
		14.8	—	—	6.1	0.32
		15.4	—	—	4.5	0.25
		17.0	—	—	3.8	0.37
		18.2	—	—	5.6	0.28
		—	—	—	6.3	0.28
		—	—	—	5.0	0.30
		—	—	—	6.8	0.31
		—	—	—	4.8	0.32
		—	—	—	5.9	0.26
		—	—	—	5.3	0.33
		20.2	—	—	9.2	0.30
		18.2	—	—	8.8	0.28
		—	—	—	4.9	0.33
		—	—	—	2.2	0.32
Ibi (Nagashima) (Kwansai Ry.)	200' (Double Warren Girder)	17.4	18.0	17.7	3.9	0.36
		17.5	19.0	18.3	8.2	0.32
		—	18.2	—	4.4	0.46
		—	18.5	—	2.7	0.59
		—	16.5	—	5.6	0.44
		—	13.6	—	1.9	0.53
Ōi (Kanaya) (Gov. Ry.)	200' ,, (No. 10 Girder)	—	—	—	—	—
		—	—	—	—	—
		26.2	24.0	25.1	7.2	0.39
		—	13.0	—	2.5	0.35
		—	15.8	—	3.8	0.40
		21.0	19.0	20.0	3.4	0.38
		—	—	—	0.4	0.37

CONT.

Transverse Vibration. 2a (mm)	Transverse Vibration. T (s)	Longitudinal Vibration. 2a (mm)	Time taken by Locomotive in passing over the Girder or Truss. (s)	No. of Locomotive.	Train.
11.5	0.92	1.5	2.6	325	Up, Goods Train, 10 Wagons.
2.7	—	1.0	3.2	74	Down, Mixed „ { Goods, 1 Wags. Pass, 6 Cars.
8.1	1.15	1.0	2.6	299	Up, „ „ { Goods, 6 Wags. Pass, 6 Cars.
6.6	0.67	1.4	3.4	325	Down, Goods „ , 11 Wagons.
—	—	—	3.0	—	Up, „ „ „
3.8	0.99	1.0	3.3	325	Down. „ „ , 11 Wagons.
—	—	—	2.6	325	Up, Mixed „ , { Goods, 2 Wags. Pass., 8 Cars.
7.2	0.99	0.7	—	324	Down, Goods „ , 12 Wagons.
2.9	0.28	0.7	—	74	„ , Mixed „ , { Pass., 6 Cars. Goods, 4 Wags.
8.9	1.25	0.8	—	324	Down, Goods, „ , 12 Wagons.
11.5	1.21	—	4.8	505	Up, „ „
15.0	1.09	—	4.0	„	Down, „ „
12.0	1.24	—	4.8	„	Up, „ „
11.0	1.27	0.6	4.2	„	Down „ „
10.8	1.21	0.8	4.0	„	Down „ „
12.5	1.48	0.5	6.0	„	Up „ „
4.7	0.50	0.5	—	42	Up, Mixed Train, { Pass., 6 Cars. Goods, 18 Wags.
—	—	—	5.3	41	Up, Passenger „ , 10 Carriages.
—	—	—	5.0	41	Down, „ „ , „ „
—	—	—	6.0	40	Up, Mixed „ , { Pass., 10 Cars. Goods, 5 Wags.
5.0	0.60	0.7	—	40	Down, Passenger „ 10 Carriages.
5.4	1.12	0.7	—	41	Up, Mixed „ , { Pass., 6 Cars. Goods, 6 Wags.
6.5	1.12	1.3	—	27	Down, „ „ , { Pass., 6 Cars. Goods, 9 Wags.
8.0	0.94	—	—	606	Up, Mixed „ , { Pass., 5 Cars. Goods, 10 Wags.
6.0	0.66	—	—	605	Down, „ „ , { Pass., 8 Cars. Goods, 8 Wags.
3.8	0.81	—	7.0	{ 608 and 2, in series.	Up, Passenger „ , 18 Carriages.
5.8	0.76	—	—	634	Down, Mixed „ , { Pass., 6 Cars. Goods, 20 Wags.
3.4	0.79	—	—	640	„ , Passenger „ 17 Carriages.
12.4	0.74	—	—	{ 610 and 113, in series.	Up, Mixed „ , { Pass., 6 Cars. Goods, 10 Wags.
—	—	—	—	{ Two workmen run going and returning.	—

TABLE II.

River.	Bridge Girder or Truss.	Deflection. Instrumentally measured. (mm)	Deflection. Directly measured (mm)	Deflection. Mean. (mm)	Vertical Vibration. 2a (mm)	Vertical Vibration. T (s)
Ōi (Kanaya) (Gov. Ry.)	200′ Double Warren Girder (No. 10 Girder)	—	—	—	4.0	0.40
		—	—	—	2.4	0.42
,,	200′ ,, (No. 14 Girder)	—	15.0	—	—	—
		—	14.8	—	—	—
Kizu (Kasagi) (Kwansei Ry.)	200′ Pratt Truss	18.2	—	—	7.3	0.43
		15.8	—	—	1.7	—
		—	—	—	5.3	0.37
		17.6	—	—	4.4	0.34
		17.4	—	—	6.1	0.31
		19.2	—	—	4.8	—
		17.0	—	—	4.5	0.37
,,	200′ ,,	—	—	—	4.5	0.37
		—	—	—	6.0	0.37
		—	—	—	5.1	0.41
		—	—	—	6.9	0.43
		—	—	—	6.8	0.42
		—	—	—	2.5	0.29
No. 3 Aizawa (Oyama) (Gov. Ry.)	200′ Bow-string Truss	—	—	—	2.2	0.36
		—	—	—	3.5	0.26
		—	—	—	4.5	0.38
,,	200′ ,,	—	10.5	—	—	—
		—	13.0	—	—	—
		—	11.8	—	—	—
		—	11.6	—	—	—
		—	11.3	—	—	—

CONT.

Transverse Vibration. 2a (mm)	Transverse Vibration. T (s)	Longitudinal Vibration. 2a (mm)	Time taken by Locomotive in passing over the girder or truss. (s)	No. of Locomotive.	Train.
5.8	—	—	—	608	Up, Goods Train, 24 Wagons
6.8	0.88	—	—	612	Down, „ „ , 18 „
—	—	—	—	608	Mixed „ , {Pass., 6 Cars. Goods, 4 Wags.
—	—	—	—	312	Down, Goods „ , 12 Wagons.
—	—	—	6.0	35	„ , „ „ , 11 „
—	—	—	4.7	33	„ , Passenger „ , 12 Carriages
—	—	—	5.4	30	Up, „ „ , 11 „
—	—	—	4.7	35	„ , Goods Train, 11 Wagons
—	—	—	5.6	31	Down, Pass. „ , 10 Carriages
—	—	—	4.7	36	„ , „ „ , 10 „
—	—	—	6.0	38	„ , Mixed „ , {Pass., 1 Cars. Goods, 11 Wags.
2.3	0.65	1.4	—	29	Up, Passenger „ , 11 Carriages
3.1	0.71	1.6	—	33	Down, „ „ , 16 „
1.2	0.61	1.3	—	38	„ , Goods „ , 6 Wagons
2.3	0.26	1.3	—	33	Up, Passenger „ , 11 Carriages
2.7	0.45	1.0	—	38	„ , Goods „ , 8 Wagons
1.9	0.77	1.5	—	35	Down, Pass. „ , 10 Carriages
—	—	—	5.6	272	Up, Passenger „ , 9 Carriages
—	—	—	5.3	{188 and 200, in series.	„ , Goods „ , 28 Wagons
—	—	—	6.6	{187 and 191, in series.	„ , Passenger „ , 18 Carriages
—	—	—	—	272	
—	—	—	—	193	
—	—	—	—	200	
—	—	—	—	278	
—	—	—	—	203	

TABLE II.

River.	Bridge Girder or Truss.	Deflection. Instrumentally measured. (mm)	Directly measured (mm)	Mean (mm)	Vertical Vibration. 2a (mm)	T (s)
Tone (Toride) (Nippon Ry.)	200′(Double Warren Girder) (1st Girder from Tokyo side)	—	17.5	—	—	—
		—	25.4	—	—	—
		—	29.5	—	—	—
„ „	200′ (Double Warren Girder) (2nd Girder from Tokyo side)	—	—	—	2.6	0.35
		—	—	—	4.0	0.46
		—	—	—	5.6	0.43
		—	—	—	4.5	0.44
„ „	200′ („) („)	—	—	—	8.5	0.40
		—	—	—	4.5	0.50
		—	—	—	7.3	0.41
No. 3 Sakawa (Yamakita.) (Gov. Ry.)	200′ (Bow-string Truss)	—	—	—	4.5	0.34

CONT.

Transverse Vibration.		Longitudinal Vibration.	Time taken by Locomotive in passing over the Girder or Truss.	No. of Locomotive.	Train.
2a (mm)	T (s)	2a (mm)	(s)		
—	—	—	—	123	Down, Goods Train.
—	—	—	—	527	Up, Mixed „
—	—	—	—	211 and 510, in series.	Down, „ „
3.1	—	0.5	—	555	„ , Goods Train.
5.8	0.93	1.0	—	515	Up, Mixed „
4.6	1.00	0.7	—	513	Down, „ „
4.7	0.91 0.45	0.7	—	553	Up, Goods „
4.8	0.86	0.7	—	123	Down, „ „
5.0	0.90	1.0	—	527	Up, Mixed „
6.8	1.20	0.7	—	211 and 510, in series.	Down, „ „
5.5	0.39	3.4	—	190 and 272, in series.	Up, Passenger „

TABLE III.—SUMMARY OF THE DEFLECTION AND VIBRATION MEASUREMENTS.

Bridge Girder or Truss.	Deflection		Vertical Vibration				Transverse Vibration				Longitudinal Vibration	
			Max. 2a		T		Max. 2a		T			
	2a (mm)	Mean (mm)	Absolute (mm)	Mean (mm)	Longest (s)	Mean (s)	Absolute (mm)	Mean (mm)	Longest (s)	Mean (s)	Max. 2a (mm)	Mean (mm)
*Tone (Toride) 20′ Plate Girder	2.9	2.5	—	—	—	—	—	—	—	—	—	—
* „ 60′ „ „	11.1	9.9	1.5	1.2	0.26	0.23	—	—	—	—	—	—
*Kuji (Ōmika) 60′ „ „	12.5	12.4	—	—	—	—	—	—	—	—	—	—
Tone (Maebashi) 70′ „ „	9.9	8.8	2.6	1.9	0.22	0.20	5.0	3.4	0.43	0.38	1.0	0.4
*Kizu (Kasagi) 70′ „ „	16.3	15.4	—	—	—	—	—	—	—	—	—	—
*Kuji (Ōmika) 100′ Warren	17.8	16.2	5.6	4.8	0.35	0.34	10.0	9.5	1.06	0.82	0.9	0.7
*No. 2. Sakawa (Yamakita) 100′ „	14.7	13.2	5.6	4.0	0.35	0.31	10.2	7.5	1.09	0.93	2.7	2.0
*No. 3. „ („) 100′ „	15.4	—	5.1	—	0.29	—	—	—	—	—	—	—
Kizu (Kasagi) 100′ „	14.0	10.9	4.7	3.1	0.30	0.27	—					
„ („) 100′ „	10.2	10.0	—	—	—	—	—	—	—	—	—	—
Ibi (Nagashima) 120′ Pratt	8.0	6.8	1.6	1.3	0.28	0.25	—	—	—	—	—	—
*No. 3. Aizawa (Oyama) 105′ Pratt Deck	25.4	23.9	5.8		0.33	0.32	—	—	—	—	—	—
„ („) „ „ „	17.5	16.3	—	—	—	—	—	—	—	—	—	—
Kami-Usui (Matsuida) 105′ „ „	20.2	17.1	9.2	5.8	0.37	0.30	15.0	8.7	1.48	1.10	1.5	0.9
Ibi (Nagashima) 200′ Double Warren	18.5	17.1	8.2	4.1	0.59	0.43	6.5	5.6	1.12	0.95	1.3	0.9
*Ōi (Kanaya) 200′ „ „	25.1	18.5	7.2	3.9	0.42	0.39	12.4	6.5	0.94	0.80	—	—
„ „ „ „ „	15.0	14.9	—	—	—	—	—	—	—	—	—	—
*Tone (Toride) 200′ „ „	29.5	24.1	—	—	—	—	—	—	—	—	—	—
* „ („) „ „ „	—	—	8.5	5.3	0.50	0.43	6.8	5.0	1.20	0.97	1.0	0.8
Kizu (Kasagi) 200′ Pratt Deck	19.2	17.5	7.3	5.1	0.43	0.37	3.1	2.3	0.77	0.69	1.6	1.4
*No. 3. Sakawa (Yamakita) 200′ Bow String	—	—	—	4.5	—	0.34	—	5.5	—	0.39	—	3.4
*No. 3. Aizawa (Oyama) 200′ „ „	—	—	4.5	3.4	0.38	0.33	—	—	—	—	—	—
* „ („) „ „ „	13.0	11.6	—	—	—	—	—	—	—	—	—	—
Hozu (Saga)‡ 200′ „ „	—	—	3.7	3.3	0.39	0.38	2.7	—	0.97	0.90	1.3	0.9

‡ The Hozu-*gawa* bridge vibrations were measured by Professors S. Tanabe and T. Hibi, of Kyoto Imp. Univ.

From Table III, we see that the absolutely greatest amount of the deflection reached 29.5 mm in the case of one of the 200′ double Warren girders of the Tone-*gawa* (Toride) bridge, and the next greatest amount of 25.4 mm occurred in the case of one of the 105′ Pratt *deck* truss of the No. 5 Aizawa-*gawa* bridge; each having taken place under the passage of two tender engines in series. The greatest vertical vibration of 9.2 mm, which occurred in the case of the Kami-Usui-*gawa* 105′ truss, similar to that of the last-named bridge, was produced by the passage at a velocity of 17 miles / hour of an Abt engine of 53^t 12^c coupled to a break-van; the maximum vertical motion of a girder or truss of long span generally occurring with a train running at a comparatively slow speed. The next greatest vertical vibration of 8.5 mm occurred in the case of the first-mentioned Tone-*gawa* bridge. From these figures it will be readily understood that the vertical vibration forms an element of the bridge motion of a considerable importance. The period of the vibration varied from about 0.2 sec. for 60′–70′ plate girders to nearly 0.6 sec. for the 200′ double Warren girders.

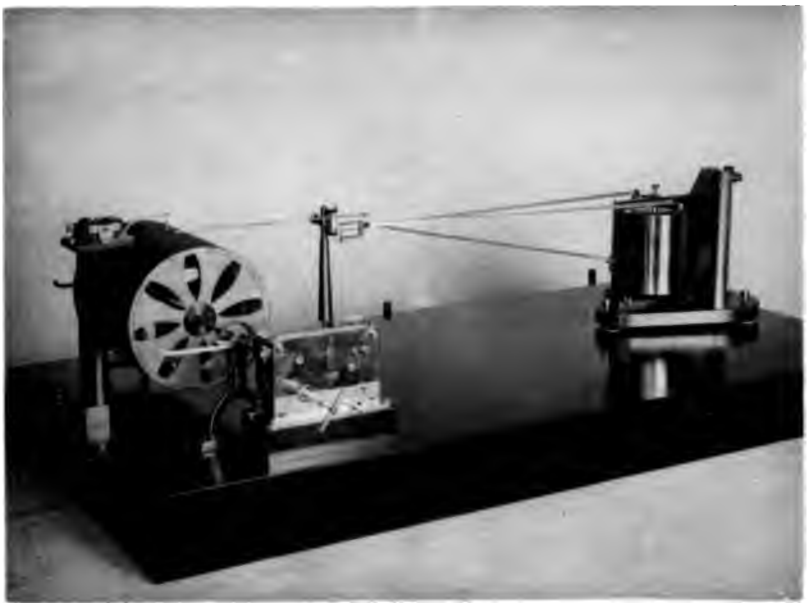
The two greatest transverse vibrations of 15.0 and 12.4 mm occurred respectively in the cases of the Kami-Usui *gawa* 105′ deck Pratt truss and one of the 200′ double Warren girders of the Ōi-*gawa* bridge; the vibration period of former bridge reaching an extraordinary length of nearly 1½ sec. The length of the transverse period was generally more than double the vertical period.

The longitudinal vibrations were always very quick, and I was not able to satisfactorily measure their periods with the instruments then used. The amplitude of these movements was small, varying between 0.9 and 2.7 mm for the different girders and trusses. In virtue of the great intensity or violence, the longi-

tudinal motion, although small, must play an important part in the process of loosening the rivets, or wearing the joints, and its study will prove of great value in connection with the strength of the bridge structures.

A careful study of the results of the measurements given in Tables II and III will disclose many interesting points. Amongst others, it will be observed that a weak bridge has a larger range (double amplitude) as well as a longer period than a strong bridge, the vibration elements being, so to speak, the indices of the strength or quality of a given elastic structure.

A Horizontal Tremor-Recorder.



Deflection Measurer.

Horizontal Tremor Recorder.

By

F. Omori, Sc., D.,

Member of the Imperial Earthquake Investigation Committee.

In the *Publications*, No. 18, I have described a form of horizontal tremor recorder designed to measure the small vibrations of the ground due to artificial causes. Since then several instruments of the same type, adapted to a continuous seismic registration, have been constructed, the two horizontal component vibrations being written on a smoked paper wrapped round a revolving cylinder in the usual way. These seismographs, with a magnification of about 100, set up in the Mount Tsukuba and Osaka Meteorological Observatories proved very useful in the observation of near earthquakes, or those, say, of the epicentral distance under 1000 km.

The upper picture on Pl. XLII represents a single component "tremor recorder," whose heavy bob is 32 kg in weight, and which magnifies the motion 200 times.

Although the observation of the teleseismic disturbance is very important, it must not be forgotten that the chief interest of the earthquake measurements is in connection with the study of local shocks. For an earthquake country it will be more to the purpose to provide the different stations with the "tremor recorders," or similar instruments, together with ordinary seismographs for the observation of the macro-seismic disturbance; the instruments for the study of the teleseismic motion being set up only at a few standard observatories.

Long Period Horizontal Pendulum.

By

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Member of the Imperial Earthquake Investigation Committee.

For the observation of slow vibrations occurring in the teleseismic motion it is necessary to bring the "steady mass" of a seismograph sufficiently near to the state of neutral equilibrium, so as to make the natural oscillation period of the instrument much longer than that of the earthquake movements. In the case of a horizontal pendulum, this amounts to minimizing the angle, φ, formed between the vertical and the axis of the pendulum, or the line joining the points of support and of suspension of the latter. Now, as the tendency of the pendulum to become unstable depends on the smallness of the horizontal distance between the points of support and of suspension, we can, by increasing the vertical distance between these two points, lessen the angle φ and thereby increase the oscillation period, without throwing the pendulum out of the stable condition. If the length of the horizontal strut be about 1 metre, and the vertical height of the pendulum be $2\frac{1}{2}$ to 3 metres, the oscillation period can be raised to about 3 min.*; the mass of the heavy bob employed being about 50 kg.

Pl. XLIII represents a horizontal pendulum, temporarily set up in the Seismological Laboratory; the instrumental constants being as follows :—

* See also the *Publications*, No. 4.

A Long-period Horizontal Pendulum.

Weight of the bob = 50 kg.

Length of the horizontal strut = 1 metre.

Vertical height of the pendulum = 2 metres.

Pointer multiplication = 30.

The pendulum can be adjusted without difficulty to an oscillation period of about 2^m 15^s.

The recording apparatus has received a notable improvement in the hand of H. I. H. Prince Yamashina, who takes a keen interest in meteorological and seismological observations. The mechanism is so arranged that the cylinder can be quietly rolled away horizontally and normally o its axis, enabling us to take off or put in the position the record-receiver without affecting the writing pointer.

Seismographic Diagrams of the Local Earthquake of June 11, 1907.*

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

1. Area of Disturbance. The earthquake of June 11, 1907, at 8^h 59^m 21^s a.m. (Hongō, Tokyo) was felt moderately or strongly in the vicinity of Tokyo over an area about 200 km in length and about 100 km in width. The area, within which the motion was sensible, stretched from near the northern end of the Main Island to the vicinity of Osaka, over a distance of nearly 900 km. (See Fig. 1, Pl. XLIV.) In Tokyo, the earthquake was of a moderate intensity, and, although no damage was caused, it was the strongest next to the severe shock of Feb. 24, 1906.

2. Position of the Eqke Origin. The durations of the preliminary tremor at Tokyo, Mito, and Mount Tsukuba, were respectively 8.5 sec., 9 sec., and 7.2 sec. The circles drawn about these places and centres with radii equal to the corresponding epicentral distances‡, meet each other near the origin of disturbance, whose approximate position is $\lambda=140°45'$, $\varphi=35°30'$, at about 100 km to S78°E of Tokyo. (See Fig. 1.) In Tokyo, the shock was preceded by a slight, but distinct sound.

3. Microseismograph Records. Figs. 2, 3, and 4 (Pl. XLV) give the EW, vertical, and NS component diagrams furnished by

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* The times are given in the 1st Normal Japan Time, namely, that of 135° E.

‡ Calculated according to the formula $x^{km}=7.27\ y^{sec.}+38^{km}$, where x is the epicentral distance and y is the duration of the total preliminary tremor.

the respective microseismographs. The instrumental constants are:—

EW............	Multiplication	=10;	Pendulum period	=28 sec.
Vertical	„	=12;	„	=4 „
NS	„	=30;	„	=48.5

It will be observed that the preliminary tremor was suddenly followed by the maximum vibration, the two displacements of the latter being as follows:—

1st motion = 5.1 mm, towards S70°E;
2nd „ = 6.6 „ (maximum), towards N63°W.

Thus the very first displacement of the principal portion took place approximately towards the earthquake origin, while the counter, or maximum, displacement was directed away from the latter. The vibration in question belongs evidently to the "longitudinal wave," its mean direction of S67°E—N67°W being not much different from the epicentral direction from Tokyo. For the next $1^m\ 20^s$, the motion remained active, the total duration being about 20 min. The comparative shortness of the duration, in spite of the large amplitude of the principal vibration, is the characteristic of a local shock.

For the sake of comparison, I give in Fig. 4 (Pl. XLV) the EW component diagram of the moderate earthquake of June 23, 1902, at $7^h\ 42^m\ 42^s$ A.M., recorded at Hongō by the same instrument as in Fig. 2. It will be observed that Figs. 2 and 4 are almost perfectly identical to one another; the two displacements composing the maximum vibration at the commencement of the principal portion of the earthquake here considered being respectively 5.7 mm towards E, and 7.0 mm towards W.

Figs. 6, 7, 8, and 9 (Pl. XLVI) are the EW component

diagrams of the earthquake (June 11, 1907) furnished by horizontal pendulums, as follows:—

Figs. 6...Hongo (Tokyo).	Multiplication = 30;	Pendulum period = 41.5 sec.
Figs. 7... „ („)	„ = 15;	„ = 61.5 „
Figs. 8...Hitotsubashi(„)	„ = 10;	„ = 31.1 „
Figs. 9...Mito.	„ = 20;	„ = 28.8 „

4. Macroseismograph Records. Fig. 10, Pl. XLVII, is the record furnished by a Gray Milne type macroseismograph, set up in the Seismological Institute, the magnification of the EW, NS and vertical components being respectively 5, 5, and 8. The numerals, 1, 2, 3, and 4, indicate corresponding epochs in the three components. The duration was in this case, about 6 min. The large movement at the commencement of the principal portion was as follows:—

Resultant hor. motion = 6.8 min., towards N50°W.
Vertical motion = 0.8 mm upwards.

This result is nearly similar to that indicated by the microseismographs (§3). Only the first displacement, corresponding to a single amplitude, is here very imperfectly shown, on account of the length of its period and the friction of the instrument. The subsequent and principal macro-seismic vibrations* were as follows:—

Max $2a = 1.6$ *mm*, $T = 1.6$ sec.
„ „ , $T = 0.72$ „

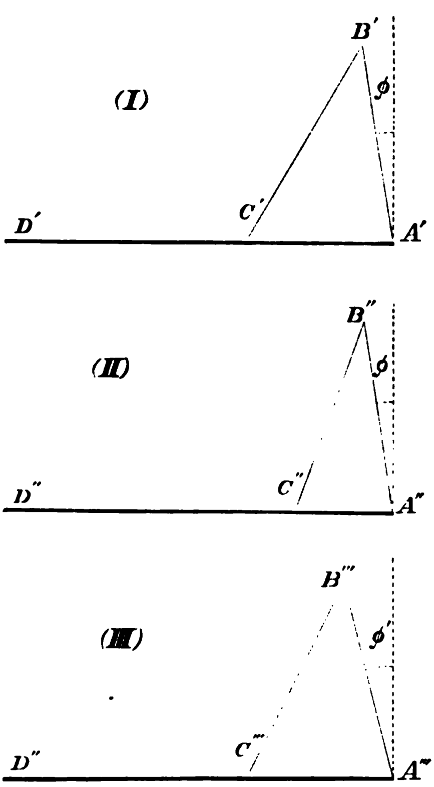
The period of the "ripples," or small sharp vibrations, was 0.20 sec.

Fig. 11 (Pl. XLVIII), is the macroseismographic record obtained at Hitotsubashi (Tokyo), the EW, NS, and vertical components being multiplied 3, 4, and 2 times, respectively.

* T and $2a$ denote as usual the complete period and the double amplitude, respectively.

The numerals, 1, 2, 3, and 4, indicate corresponding epochs in the three components. It will be observed that the movements of the macroseismic character at Hitotsubashi is more regular and much greater than at Hongo; this being the consequence of the extreme softness of the ground at the former place.

5. Tiltometer Records. The following is the principle of the experiments made to test the existence or non-existence of tilting in the ordinary or macroseismic motion, which I have carried on since 1897 at the Seismological Institute. As diagrammatically shown in the accompanying figure, let there be three horizontal pendulums, I, II, and III, in which C′, C″, C‴ are the heavy bobs; B′C′, B″C″, B‴C‴ the ties; A′C′, A″C″, A‴C‴ the struts; and C′D′, C″D″, C‴D‴ the writing pointers; the lengths A′D′ and A″D″ being equal to one another. Further, let the two pendulums, I and II, have a common angle ($=\varphi$) of inclination of the pendulum axis to the vertical, the ratios of multiplication $\frac{A'C'}{C'D'}$ and $\frac{A''C''}{C''D''}$ being unequal; while the two pendulums, I and III, have equal ratios of multiplication, $\frac{A'C'}{C'D'}$ and $\frac{A'''C'''}{C'''D'''}$, but unequal angels of inclination of the pendulum axes, φ and φ'. The three pendulums are placed with their planes parallel to one another. Thus the first two pendulums would have an equal



sensibility for a tilting motion, but different magnifications for a horizontal motion; while the first and third pendulums have an equal magnification for a horizontal motion, but different sensibilities for a tilting motion.

Fig. 12 (Pl. XLIX) is the record of the EW component motion obtained on the occasion of the earthquake of June 11, 1907, by one of the machines composed, according to the principle above explained, of the three pendulums A, B, and C, the instrumental constants being as follows:—

Pendulum.	Length of Strut.	Total length of Strut and Pointer.	Multiplication (for Hor. Motion.)	T_0	T	$\varphi=\frac{T_0^2}{T^2}$
	cm	cm		sec.	sec.	
A	12	48	4	0.70	4.36	$\varphi_A=\varphi_B$
B	7	48	7	0.51	3.31	$\varphi_B=\varphi_A$
C	7	28	4	0.53	2.50	φ_C

In the above table T_0 and T denote respectively the complete period of vibration of each pendulum when suspended vertically and when actually set up as a horizontal pendulum. The displacement of the writing index of the pointer corresponding to a tilting a is, in each case, given by the formula.

$$\gamma\ (\text{sensibility})=l\times\frac{a}{\varphi}\ .$$

From the adjustments of the three pendulums as given in the above table, we arrive at the following relations:—

$$\varphi\ (\text{for } C)=1.74\ \varphi\ (\text{for } A \text{ and } B).$$

$$\gamma\ (\text{for } A \text{ and } B)=3\gamma\ (\text{for } C).$$

Thus the two pendulums A and B ought to give, for a tilting of the ground, a record three times larger than the pendulum C;

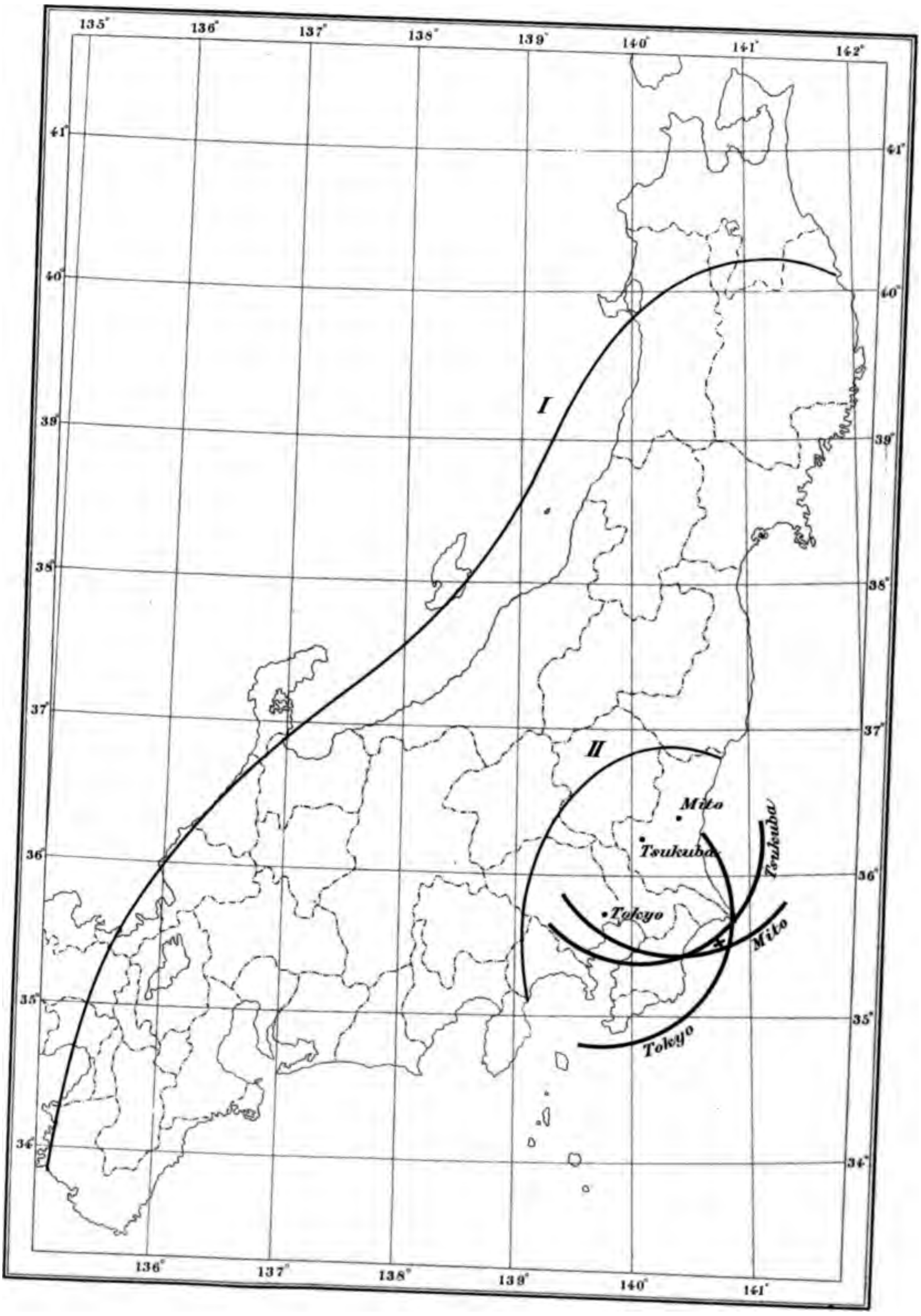
while each of the two pendulums *A* and *C* gives, for the horizontal motion, a record equal to 4/7 of that of the pendulum B.

Although different amounts of the friction in the three pendulums evidently interfered to some extent with the accuracy of the records, Pl. XLIX indicates, as well as the diagrams obtained on other occasions, that the tilting element in the ordinary earthquake motion is, if any, very slight in amount.*

The First Report on this experiment was published in No. 32 of the Japanese *Reports* of the Imp. Earthquake Inv. Comm. (1900).

Fig. 1. Earthquake of June 11, 1907.

(×)............Eqke Origin.
(I) ....Boundary of Area of Sensible Motion.
(II) ....   „   „   „ Strong or Moderate Motion.



Figs. 2, 3, and 4. Earthquake of June 11, 1907. Observed at Hongo, Tokyo.

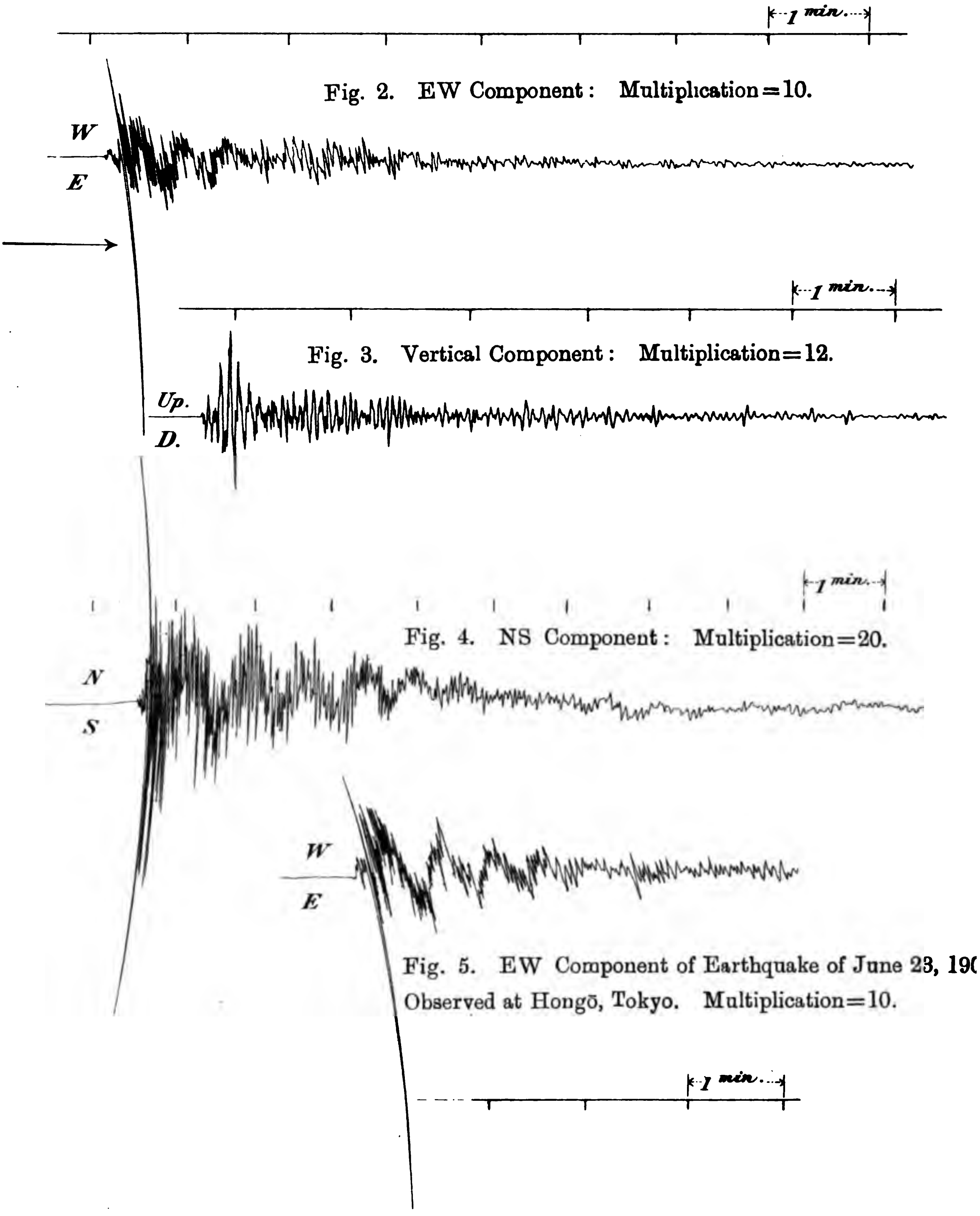


Fig. 2. EW Component: Multiplication = 10.

Fig. 3. Vertical Component: Multiplication = 12.

Fig. 4. NS Component: Multiplication = 20.

Fig. 5. EW Component of Earthquake of June 23, 19(
Observed at Hongō, Tokyo. Multiplication = 10.

Horizontal Pendulum Diagrams of Eqke of June 11, 1907.

Fig. 6. EW Component, Hongō.
Multiplication = 30.

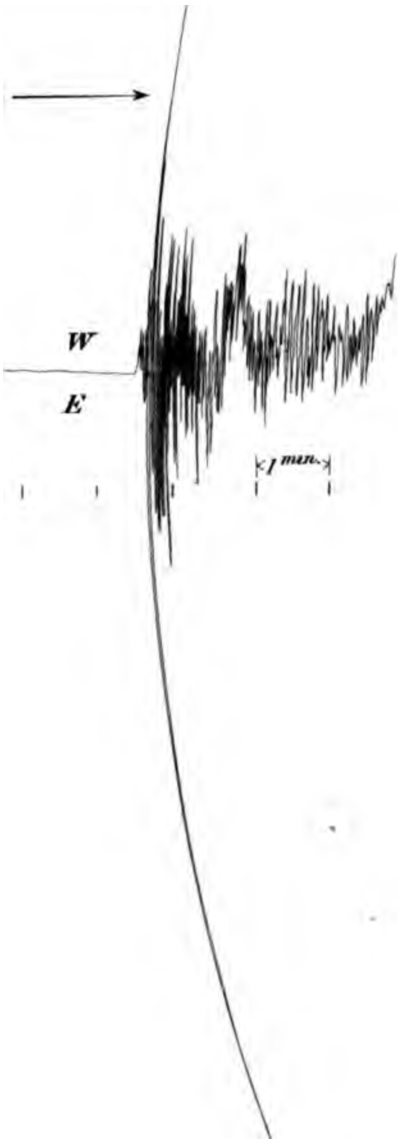


Fig. 7. EW Component, Hongō.
Multiplication = 15.

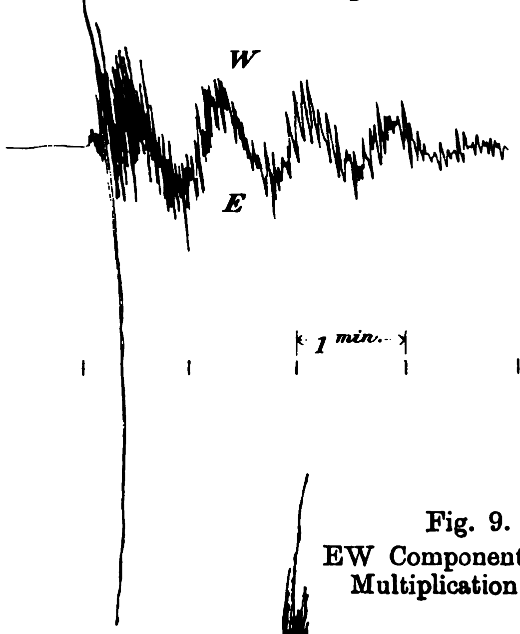


Fig. 9.
EW Component, Mito.
Multiplication = 20.

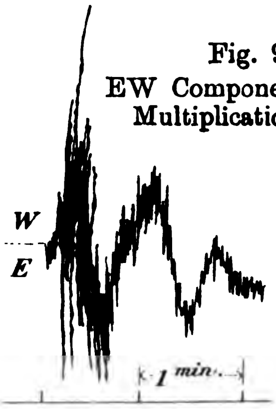
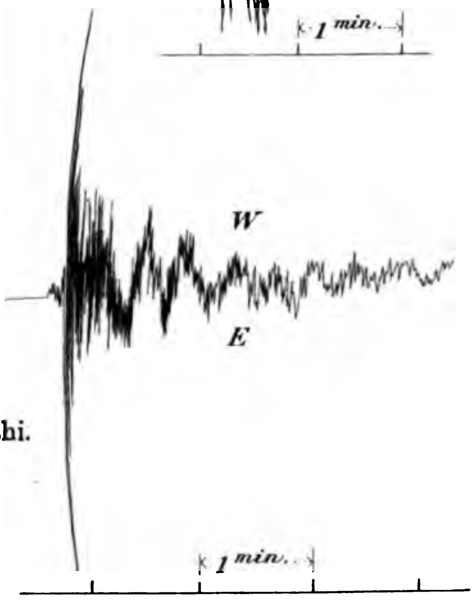


Fig. 8. EW Component, Hitotsubashi.
Multiplication = 10.



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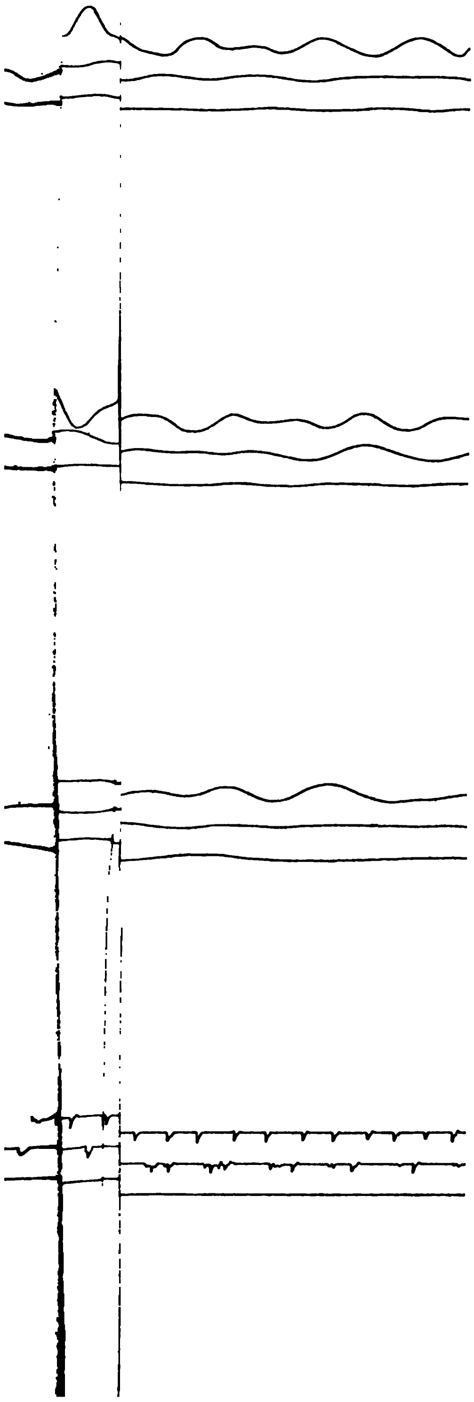
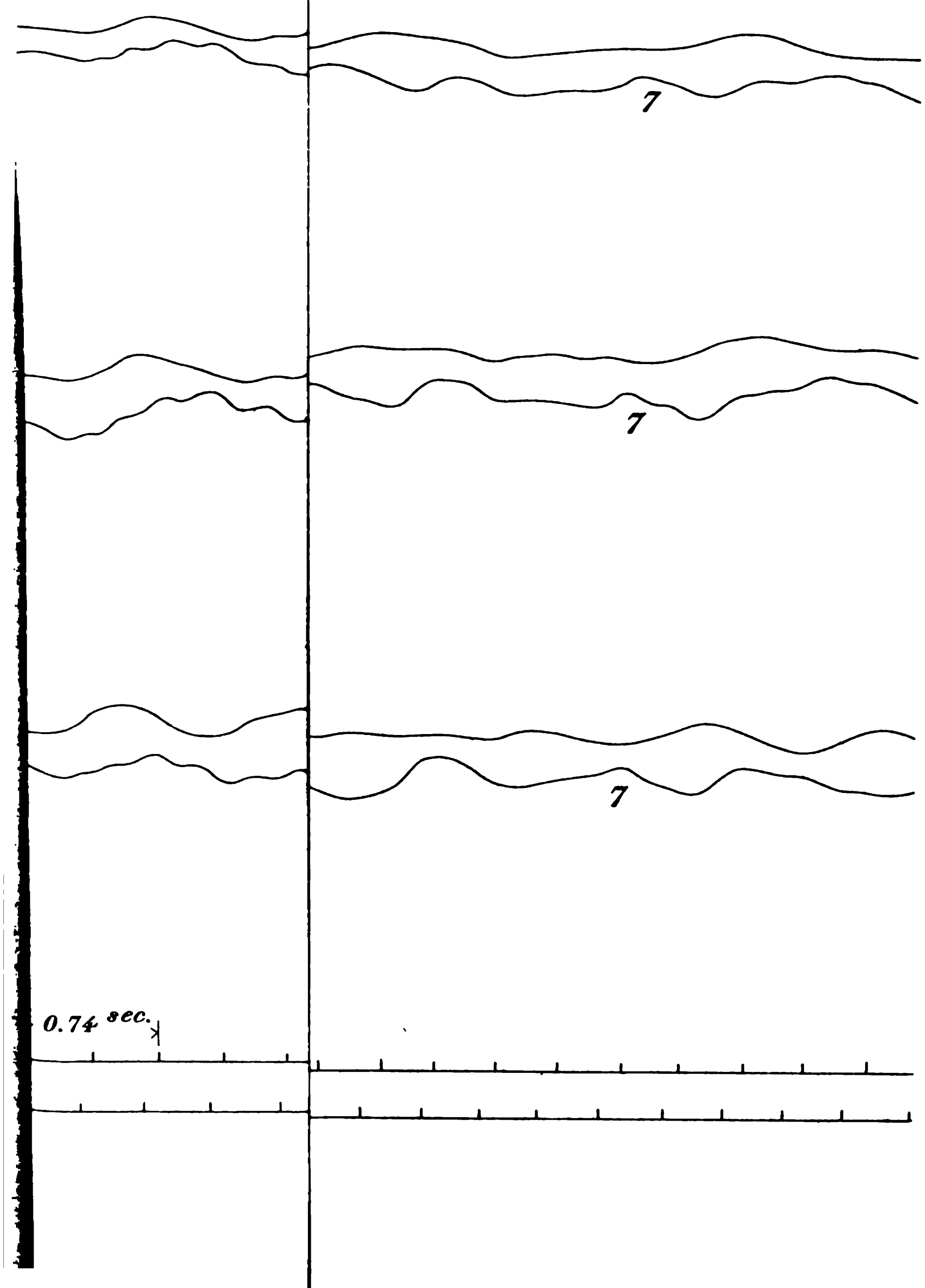
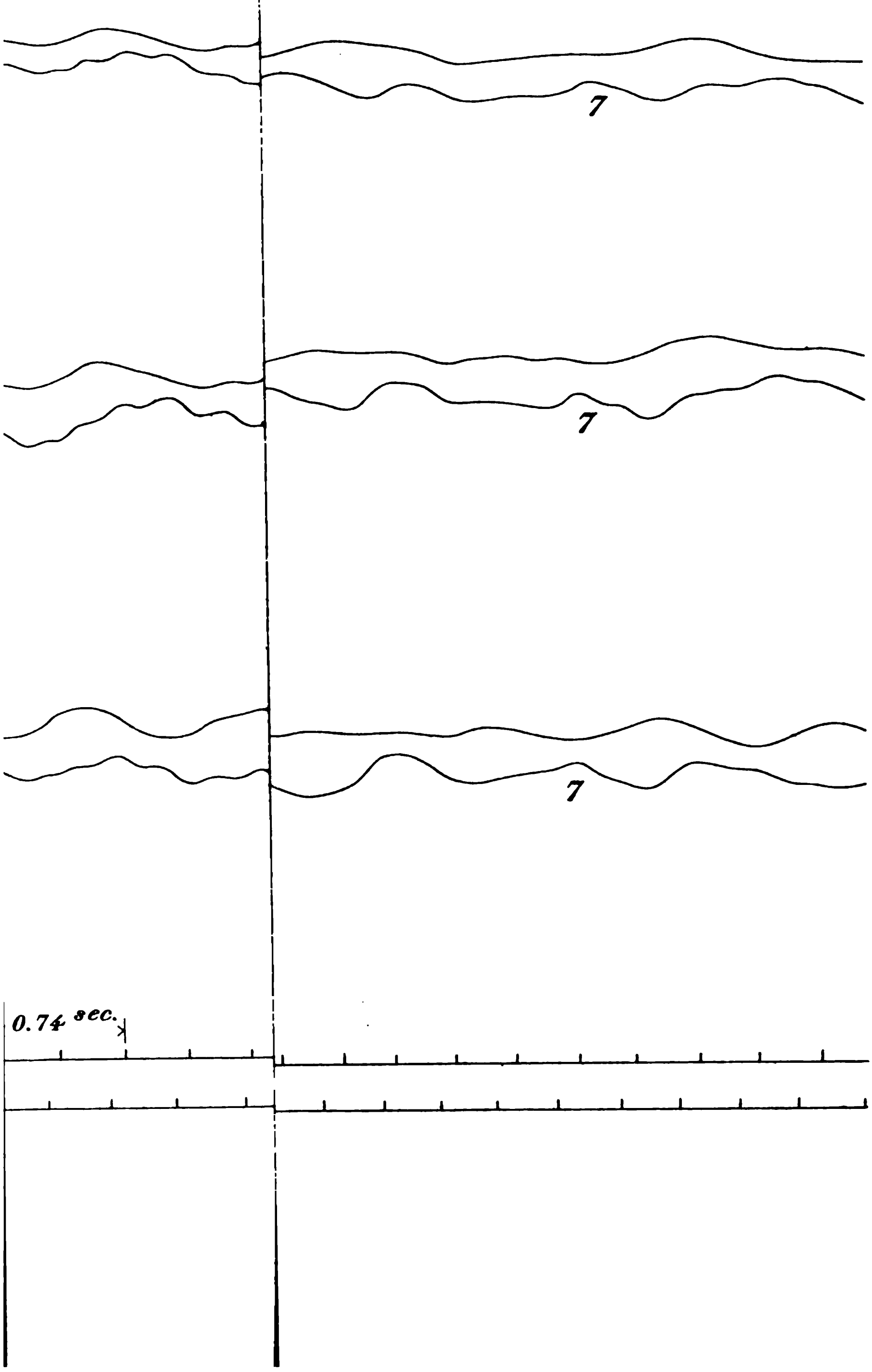


.... **Multiplication** = 4
.... „ = 7
.... „ = 4



....Multiplication = 4
....   „   = 7
....   „   = 4



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